COMPARING HISTORIC & PRESENT CONIFER SPECIES COMPOSITIONS & STRUCTURES ON FORESTED LANDSCAPES OF THE BITTERROOT FRONT

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Contract completion report for
research joint venture agreement 94928

between

Rocky Mountain Research Station
Fire Effects Unit
Missoula, Montana

and

School of Forestry -Dr. Paul Alaback
University of Montana
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Abstract: A study was initiated in 1995 to measure landscape changes in forest structures between 1900 and 1995. A systematic sampling system was used to collect data on 3 forested faces on the Bitterroot Front. Over 1200 tree cores were sampled on 216 plots between the elevation range of 4500 to 7500 feet. Historic forests were reconstructed through quantitative techniques. Changes are presented in three elevation zones: lower (4500-5800 feet), middle (5800-6900 feet) and upper (6900-7500 feet). Dramatic decreases in fire dependent species and increases in fire intolerant species are shown throughout all elevation zones. Ponderosa pine has been reduced from 51% to 26% of total basal area in lower elevations. Douglas-fir increased its relative percentage of total landscape basal area from 19% to 55% over the past century. Western Larch abundance has declined from 26% to 11% in lower elevations (4500-5800 feet) and from 24% to only 6% in middle elevations (5800-6900 feet). Lodgepole pine has increased its relative percentage of landscape basal area 6% in middle elevations and 13% in upper elevations (6900-7500 feet). Whitebark pine decreased from 39% to only 11% of total stand basal area in the upper elevation zone. Changes are further described by environment (fire group) and disturbance (logging and fire).

INTRODUCTION

One of the key limitations in implementing ecosystem management is a lack of accurate information of how forest landscapes have developed over time, reflecting both pre-Euro-American landscapes and those resulting from more recent disturbance regimes. Disturbance regimes are one of the most influential determinates of forest species composition and structure. The study of historical landscapes and forest structures can provide many insights into stand dynamics across a range of scales. Additionally, comparison of the historical structures with the present gives insights into the relation of disturbance and environment to stand development. Such understanding is essential to long-term resource planning.

In this study I attempted to describe forest species composition and stand structure across an elevational gradient both in 1900 and 1995. I also described changes that have occurred between these two time periods for individual stands. Past research has shown changes in Northern Rocky Mountain forests in the past century, however, these studies have all been limited in scope to isolated forest types (Arno et al 1995, Arno et al 1993, Gruell 1983, Habeck 1990). My purpose was to supplement these studies using a systematic sample design to collect information on a continuum of forest types and conditions across a broad environmental gradient.

A presupposition that landscapes have been adversely altered

Fire suppression and selective logging have altered species compositions in coniferous forests throughout the Northern Rockies (Habeck and Mutch 1973). The

resulting effect on compositional components has been a general decrease in fire tolerant or seral species and an increase in the numbers of shade tolerant conifers more susceptible to insects, pathogens and catastrophic wildfire. The Bitterroot Front has a long history of timber harvesting and fire suppression. No quantitative data exists to describe the extent of the effects of these shifts in disturbance regimes on landscapes.

A presupposition that 1900 conditions are more within a range of natural variation

Past conditions can serve as models of self-perpetuating ecosystems (Monnig and Byler 1992). While no single point in time can serve as the perfect model conditions, they may serve as indicators within a range of natural variation. In the past decade ecologists have come to understand that natural disturbances are an integral driving force in ecosystems (Sprugel 1991). Fire studies in Western Montana have shown that natural fire cycles have been altered in the past century (Arno et al 1997, Arno et al 1993). Previous to the alteration of the fire disturbance regimes, fires were more frequent. The presence of fire on historical landscapes has been documented on larger time scales by Mehringer et. al (1977) through charcoal sedimentation and pollen analysis. It is unrealistic to attribute shifts in forest compositions directly to climatic fluctuations without examining the shifts in disturbance regimes.

Changes in disturbance regimes on the Bitterroot Front have presumably occurred with the human settlement of the valley. Logging and fire suppression have led to a shift in forest types across western Montana (Mutch et. al 1993). My study areas (above 4500 feet elevation) were largely unaffected by logging prior to the turn of the century. It is

unlikely that this disruption in disturbance frequencies had seriously affected forest structures in 1900.

A presupposition that landscapes studies provide a better description of natural equilibria

Previous studies have documented present and past cover types in Western Montana (Habeck 1990, Arno et al. 1995, 1993). Though these studies provided insights into historical stand structures, data have been collected only in isolated stands or forest zones. Gruell (1983) produced a photographic survey using old photographs and reshooting them, but analyses here were limited to subjective interpretation and discontinuous areas. If entire landscapes are being managed then we need to know the continuity of species composition and structure on a broader scale. Studies at the landscape level can provide more accurate depictions of natural equilibria, particularly when past disturbances have not been large enough to affect the entire area (Sprugel 1991).

Describing the landscape

Forest types along an elevation gradient even within a specific geographical area can vary widely in function and composition. However, the functionality of landscape ecosystems is undoubtedly linked to the continuity or lack thereof of different forest types (Turner 1989). Studying landscapes at different scales is one way of better understanding landscape processes (Turner et. al 1995). One of my goals was to relate changes in

forests at multiple scales, in particular by elevation zones, habitat types and stands.

I chose to describe the landscape using field sampling and dendrochronological techniques to age forests and reconstruct past conditions. It is more common for researchers to make educated or informed guesses at historic conditions, but it is hard to conceptualize all potential interactions among factors which may control tree growth. Qualitative field estimates of tree ages are not as objective or accurate as quantitative approaches to measuring tree growth and identifying historic conditions. This is especially so when considering the complexity of the many species combinations and ecological zones my study area covered.

The main objectives of this study were as follows:

1.) Develop age regression equations for all conifers in study area to aid in the description of ca. 1900 forests.

2.) Describe species composition and cover types as a percentage of the landscape from 4500 to 7500 feet elevation on east facing landtypes circa 1900 and 1995.

3.) Describe the relationship of disturbance history to changes in species compositions.

4.) Describe the effect of environment on changes in species compositions.

I used field tree core data to estimate ages of trees and reconstruct historic conditions. A subsample of trees were cored, and age was calculated from current diameter using linear regression. Then age in 1900 was estimated by subtraction, and substituted into the same age-diameter equations, allowing me to estimate diameter in 1900. In essence, I 'grew trees backwards' and reconstructed historic forests through computations. The changes that have occurred in these forests since the turn of the

century are described in detail and then linked to environment as represented by fire types (Fischer and Bradley 1987) and disturbances of logging, and forest fire.

METHODS

Study area

The Bitterroot Mountain range in western Montana runs north-south for approximately 60 miles south of Missoula, Montana. The mountain peaks in the range are separated by a series of east running, parallel tributaries to the Bitterroot River. These tributaries form breaks between triangular mountain faces giving the range a striking isomorphic pattern (Fig. 1). The mountains extend from dry grasslands in the valley floor bottom at approximately 3400 feet up to barren rocky peaks above 9,000 feet that can remain snow covered all year long. Precipitation increases with elevation with less than 13 inches of rain per year on the valley floors to 40 to 50 inches of rain in the timberline zones. The soils are of a granitic base as the Bitterroot range is part of the huge expanse of the granitic Idaho batholith (Alt and Hyndman 1991). The Bitterroot soils are rather acidic, nutrient availability poor and soil development slow. A mylonite zone makes up the smooth east face of the Bitterroot front tilting downward at an average of 25 degrees (Alt and Hyndman 1991). A wide variety of forest types are represented along an elevational gradient of the Bitterroot Front. The distribution of the forest zones on this gradient is shown in Fig. 2.

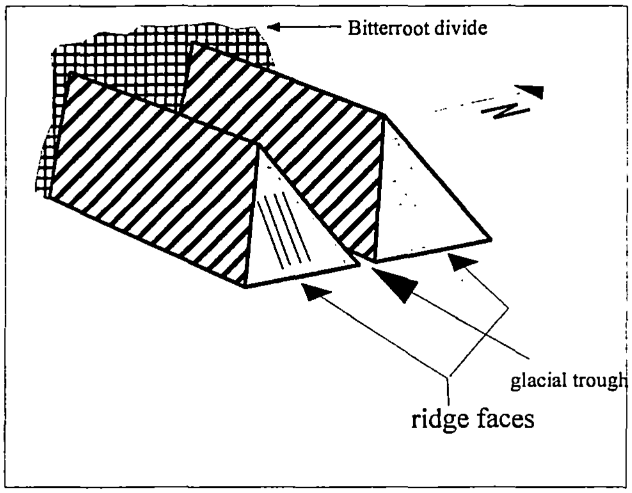

FIG. 1. Basic geomorphology of the Bitterroot Front, drainages and divide. Left face shows placement of sample transects on a mountain.

The forest types can be divided into three general forest zones by seral species: ponderosa pine, lodgepole pine and whitebark pine. The lowest elevational zone in the study areas, from 4500 to 5800 is occupied by ponderosa pine. Within this lower elevational range ponderosa pine is associated with range grasses in the driest areas and subalpine fir in the wettest. This zone historically experienced frequent, low-intensity fires which burned by fine ground fuels and small Douglas-fir and true firs. Ponderosa pine and western larch coexist as fire adapted species and individual trees can survive numerous forest fires. Fire intolerant Douglas-fir, subalpine fir and grand fir are also found in this zone. This zone has been subject to heavy timber harvesting in the past 100 years.

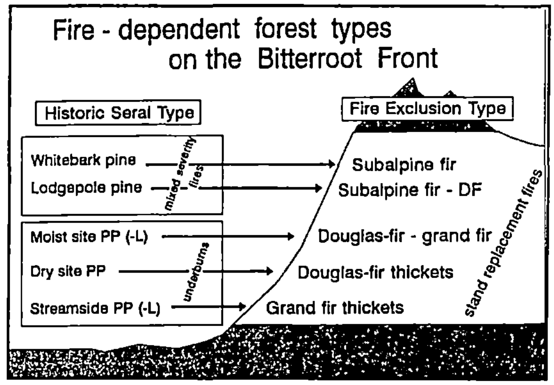

FIG 2. Distribution of forest types along the Bitterroot Front. Indicated historical and fire exclusion types were proposed by Arno (1996).

Moving to the lodgepole pine zone between 5800 and 6900 feet, the frequency of fire decreases. This zone is located dead center between lower-dry and upper-alpine timberlines. The frequency of fire and moister conditions can lead to different ecological roles of species. Here, Douglas-fir takes on the role of a seral species by developing thicker, heat insulating bark in the longer fire intervals. It is popular belief that fires in this forest type always occur as 'catastrophic' or stand replacing events, however, the severity of fires in this middle elevational zone is actually highly variable. Fires will sometimes kill only a few trees in the stand leaving lodgepole and Douglas-fir survivors.

Under less volatile conditions, fires may burn as non-lethal events similar to those in the ponderosa pine zone. But, commonly, the less frequent fires lead to high fuel concentrations which can result in more intense fires. Other disturbances in this zone include episodic outbreaks of bark beetles associated with forest fire and drought conditions. Beetles not only put pressure on the lodgepole zone but affect the higher neighboring whitebark pine areas.

The whitebark zone extends up above 6900 feet and is dominated by the presence of whitebark pine, subalpine fir, lodgepole pine and alpine larch. The landscape in these zones is patchy and broken by rock outcrops. Fire severity in these types is variable and similar to that of the lodgepole pine zone. Extreme diurnal temperature changes and heavy snowfall characterize this elevational range. While all of these forest systems were historically driven by forest fires, insect outbreaks and other natural phenomena, human activities play a role in shaping the present ecosystems.

The Bitterroot Mountains have a long history of anthropogenic disturbance. Native American burning had a significant impact on the forests in western Montana (Barrett 1982). Early settlement of the Bitterroot Valley brought heavy sheep grazing, presumably affecting fine fuels in the grasslands and reducing the potential for fire spread from the valley floor. In the late 1800's the economy of Montana began to boom. Mining and railroad industries and need for building materials sparked a massive effort to extract timber from the Bitterroot Front. Some historical accounts describe forests in the Bitterroot being clearcut up to 5,000 feet elevation before 1920 (Dr. Robert Philip, local historian, *personal communication* 1995). Fire suppression has become extremely

effective since the 1930's with the incorporation of modern fire fighting techniques by the Forest Service. Timber harvesting has taken place higher and higher on the front with time. Over the last century, harvesting has extended from the lower dry pine types to high elevation subalpine forests.

Location of transects on mountain faces

I sampled three forested faces on the Bitterroot Front using a grid (parallel transects) to locate plots (Fig. 3). On two of the faces (Cow Creek Face and Larry Creek Face) we sampled between the elevations of 4500 and 7500 feet. At the end of the field season we located an additional site (Sweeney Creek Face) in a lodgepole pine zone between 5800 and 6800 feet.

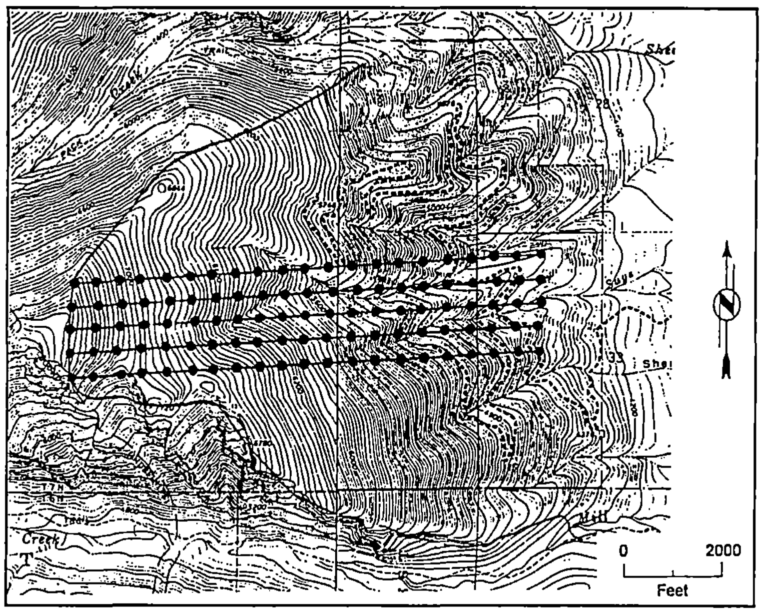

FIG. 3. Location of sample plots along transects on Cow Creek face, just northwest of Hamilton, Montana.

The average size of the three ridge faces is 1900 acres. These are the highly visible, triangular, east-facing, unglaciated ridge faces one sees when traveling through the Bitterroot Valley (Fig. 1). We made selections based on accessibility and size, and limited to areas of public ownership. Only the more common, wider ridges larger than

1000 acres were included as possible selections. Faces chosen had to have reasonable access to around 6000 feet and not be severely disturbed. I consulted members of the Bitterroot Ecosystem Management Team in locating areas meeting the above criteria.

Transects were located within the sampling units from elevations of 4500 feet to 7500 feet. The elevations above 4500 feet have had minimal logging and human started fires, thus evidence of previous stands have not been totally removed. Most areas below 4500 feet had early logging and burning activity so old that stumps and evidence of previous stands have been severely diminished. The elevational range of the study areas contained dry ponderosa pine types at the lowest and lodgepole pine/whitebark pine types in the highest elevations. The transects were primarily located in, but not confined to, the following landtypes as described by the Bitterroot National Forest (USDA Forest Service, 1993):

Landtype	Description
30	Steep mountain slopes
31	Dissected mountain slopes
32	Moderately steep mountain slopes
33	Mountain uplands and ridges

These areas cover the faces with more easterly aspects and generally avoid the steep canyon walls which line the glacial troughs.

Plots were located along a square grid at 500 feet intervals. Arno et. al. (1993) suggested that plot spacings less than 1000 feet would be adequate to capture most stand mosaic patterns; however, their study was limited to smooth slopes of subalpine/lodgepole pine types. The lower elevations contain more variation in landscape

morphology so closer plot spacings of 500 feet were used. We pre-determined sample plot locations in each unit by imposing four to five transects on 7.5 minute topographic maps (Fig 3). Plot location grids were randomly located on the center of each ridge face. The transects cover from 31-39% of each face and individual plots on the grids represent 10 acre square patches. Approximately 100 plots each were located on Larry Creek and Cow Creek faces and 30 plots on Sweeney face. Using this systematic sampling design, we were able to capture circular disturbances and vegetation communities greater than 7.3 acres in size.

Plot location

Plots were field located by using aerial photographs and topographic maps. Once a landmarker was located on the photo and ground, a hand held compass, clinometer and 100 meter tape were used to navigate to the predetermined plot centers. A transect log (Appendix A) was used to record distance, azimuth, percent slope and cumulative distance traveled on the transect lines. Intermediate points were specifically located at obvious habitat type boundaries and landmarks (road crossings, unique stands, etc.). At each of these points, changes in habitat types and forest structures (Appendix A) were noted. Plots were rejected where road construction or skid trails had removed evidence of previous stands. Plots located in riparian areas with standing or running water were also rejected to limit sampling to the upland forest types.

Plot sampling

Plot centers were marked with survey flags. A telescoping plot method was used at each plot center to tally live conifers, snags and stumps. Standard plot size was 1/10th acre (37.2 foot radius). An alternate plot size of 1/5th acre (52.7 foot radius) was utilized where less than 60 live trees per acre greater than 6 inches were found. The purpose of the telescoping plot was to capture the variation in the less dense, lower and extreme upper elevations where tree spacings may be much wider.

For each plot a data sheet was completed (Appendix B). Date, time, habitat type (Pfister et al 1977), and slope position were recorded. Aspect and slope were measured with a hand held compass and clinometer. Exact point locations were documented with a Trimble Geoexplorer GPS device. No less than 90 points were recorded at each plot with the GPS device, as recommended by the unit manufacturer, to obtain five meter accuracy.

Live trees, standing dead and downed overstory were recorded by species and 2-inch DBH class inside the 1/10th acre plot. The larger plot size was used only where the density of trees greater than 6 inches was less than 60 per acre, otherwise the standard plot size was utilized.

Only snags that were at least 6 inches in diameter at breast height at time of death were recorded by species and diameter. If bark cambium and sapwood had rotted away an ocular estimate of outside bark diameter was made. Decay classes of Maser et al (1979) were assigned to snags (Appendix C); these decay classes were later used to estimate time since death. Evidence of mortality inducing disturbance agents such as root rot, beetle galleries or fire were recorded in a summary of disturbance history.

Age structure was characterized at each plot by subsampling each cohort group. Live trees were subsampled through increment coring to estimate the number of cohorts and their respective ages. The individual cohorts then were identified by a number of factors including: tree core field counts, canopy position, vigor, bark appearance, branch and stem diameters. A cohort was defined as an age class which appeared to result from some type of disturbance or opening of growing space. The cohort which tallied trees belonged to was indicated on the data sheets by circling tally dots.

In order to estimate ages of cohorts, I first identified dominant seral or pioneering species and assigned age class(es) to these based on tree core field counts. These species are commonly the most disturbance resilient. Next, the largest fire intolerant species was sampled, taking enough samples until all the dominant and co-dominant individuals in the stand could be placed in a cohort(s). Generally, the smaller trees in the stand were not sampled. A preliminary field count was made on each core and an identification number assigned to it for reference in the office. The diameter of the tree and the field count from the core was recorded on the data sheet. Any releases or abnormal changes in growth rates were also recorded on the data sheets.

Stump diameters and heights were measured and recorded. Stump species was determined through bark and wood characteristics. Ages of stumps at time of cutting were estimated if the rings were visible. Some stumps had indiscernible growth rings, thus a rough age-diameter correlation was later used to estimate ages. Time of cutting was estimated by a number of observations including: evidence of logging equipment used, release or regeneration of present stand, stump decay, logging records. The

decompositional state of the stumps helped to identify only broad time periods of cutting as decay rates can be variable between different sites.

Evidence of logging practices indicated general periods when logging took place. Tall, highly decayed stumps usually indicate cutting before the chainsaw came into common use. Rough cuts from axe blows were indicative of cutting prior to pre-chainsaw days, or pre-1930. Large skid trails from crawler tractors indicate a period of mechanized forestry which started in the 1930's. Aerial photographs from 1937 indicated areas of early logging and road construction. Detailed records of silvicultural history were obtained from the Stevensville Ranger District. Unfortunately, the records are complete only from the early 1960's. These records proved to be useful in determining at least partial stand histories.

The final stage in the plot sampling procedure was an on-site description of stand history. The number of logging entries was recorded and the decade of each estimated. Fire scars or other evidence of wildfires or prescribed fires was recorded. Other disturbances recorded include: root rot, insect outbreaks, and wind damage. A brief description of evidence from previous stand was made at each plot. Descriptions may include: species-cohort associations, general stand appearance (e.g., dominant seral ponderosa, sub-dominant western larch with sapling Douglas-fir).

Fire scar sampling

In an effort to capture and describe the fire history of the study areas, fire scars were collected from the lodgepole pine and whitebark pine zones. Fire histories were not

executed for the ponderosa pine zones as the fire histories in these areas are too complex for the scope of this study. When plot sampling was completed on each front I perused over the data sheets and identified the plots in which I noted fire scars. Methods of Arno and Sneck (1977) were used to sample fire scars.

Scars were sampled from stumps and live trees. No fire scars were collected below 5800 feet. Most of the scars collected were from lodgepole pine. Some ponderosa pine inhabiting its extreme, upper elevations provided multiple fire scars. Scars were not collected from every plot, but fire dates were assigned to each plot based on age-classes of live trees and observational notes on plot sheets in conjunction with fire scars sampled near plots. All fire dates included in the analyses were confirmed with fire scars. Fire events on each plot were given a severity classification of non-lethal, mixed-mortality, or stand replacement.

Data analysis

Dendrochronological techniques

In the lab, cores were permanently mounted to grooved boards. Once dry, the cores were sanded on the boards using medium and fine sandpaper. The sanding smooths rough core surfaces making the rings more easily discernable. The rings for each core were then counted under a binocular microscope. Off center cores were age corrected using early growth rates and radial distance from earliest ring to estimated pith location.

Development of age regressions

For all tallied trees, age was estimated by developing regression equations to predict age from diameter and environmental variables. Conifer growth will vary interspecifically and across a spectrum of growth environments (Oliver and Larson 1990). Accordingly, accurate historic descriptions depend on modeling growth of individual trees by species and environment. It would have been ideal to develop separate regressions for each individual habitat type but I did not have adequate sample distribution. Instead, I stratified by fire groups, which are essentially conglomerates of similar habitat types (Fischer and Bradley 1987). If stratifying by fire groups did not improve the mean squared error and coefficient of correlation (R^2), all fire groups were compiled into a generalized model.

Tree diameter growth is logarithmic because less growth is added after individuals mature. Thus, a logarithmic transformation was used on all the diameter and age data to linearize these relationships. The logarithmic transformation also had the advantage of forcing equations through the origin whereas untransformed data may have underestimated ages for the smallest of trees.

Age relationships were examined through an exploratory analysis of their linear relationships to elevation, fire group, Stage's slope-aspect classification (Stage 1976) and stand basal area. The viability of using linear regressions to check age-diameter relationships was examined by checking the residuals for normal distribution and equal variances across all values of the independent variable. A goodness-of-fit-test was used to select subsets of continuous variables that served as the best predictors for linear

models. I used the SAS RSQUARE procedure for this test (SAS Institute Inc. 1985). Initial analyses included all plots regardless of fire group or disturbance history. This analysis was used to select the variables for the age equations. Models were selected for the least number of variables while still maintaining the lowest SE and highest R^2. If the goodness-of-fit-tests above did not provide acceptable statistics, trees were grouped by fire group or age-classes. Age-class groups were defined by disturbance history. I required a minimum of 30 observations to produce a reliable regression equation. Where fire or disturbance group and linear relationships were improved by separate groupings, I developed separate models for each. A bimodal distribution in lodgepole pine ages prevented the use of a single linear equation (Fig. 4). In order to assign ages to tallied lodgepole pine trees I divided the data and created two equations; one equation for each cluster of data points. Logarithmic equations appeared to overestimate the ages of small diameter trees so for trees less than six inches I used untransformed linear models forced through the origin. Information collected in the field to differentiate cohorts in the tallied trees was used to designate which equation applied to each individual tree.

The regression model for subalpine fir was different because its age-diameter distribution was not skewed or bimodal but rather amorphic (Figure 5). Subgrouping by fire types did not improve linear relationships. I used a site specific analysis based on the oldest subalpine fir cored on each plot. The diameter-age relationship of this oldest individual formed the basis of a logarithmic model for younger trees. This was done by using a model in form of :

$$MAXAGE= e^{\ln(DIA)*k} \qquad eq.\ 1$$

and solving for k, where,

$$k=\ln(MAXAGE)/\ln(DIA) \qquad eq.\ 2$$

DIA=The Diameter at breast height of the oldest tree cored
MAXAGE=Age of oldest tree cored.

The rest of the trees on plot then were assigned ages by

$$AGE=e^{\ln(DBH)*k} \qquad eq.\ 3$$

where DBH=diameter at breast height for any given tree.

The equations formed a basis for reconstructing historic forests. They were used to assign ages to all live trees, thus indicating whether or not trees were alive near the 1900. They also allowed me assign growth rates to these trees, giving quantitative descriptions of growth by environment and species.

Reconstruction

I used reverse regressions of the equations developed above to estimate tree diameters in 1900 for all species but lodgepole pine and subalpine fir. The growth of lodgepole pine and subalpine fir since 1900 was measured from increment cores. This would have been the most desirable way to estimate plot growth for each species but this is very time consuming work and could only be afforded for these two species. This growth was related as a linear function of

$$RG= DBH\ (x) + constant \qquad eq.\ 4$$

RG=Radial growth
DBH= diameter at breast height
x=regression coefficient.

Reconstruction of the ca. 1900 forests occurred through an analysis of three relics from that time period: live trees, dead trees and stumps. Each type of relic was handled in a different way. The foundation for the analyses was to first calculate an age for the observation. The second part was to estimate a time of death if it was a stump or snag. The last part was to estimate the amount of growth that had occurred since 1900.

The live trees were all assigned ages from the regressions discussed in the previous section. Ninety-five years were subtracted from the calculated 1995 age to get the age at 1900. The age-regressions were algebraically manipulated to solve for ca. 1900 diameter. For example, and expression of

$$\text{Age} = \text{B*Diameter} + \text{C*Elevation} + \text{Constant} \qquad \textit{eq. 5}$$

where B and C are regression coefficients, was changed to

$$\text{Diameter} = (\text{C*Elevation} - \text{Age} + \text{Constant}) / \text{B} \qquad \textit{eq. 6}$$

By inserting 1900 age and elevation into this equation along with the other coefficients and constants, the 1900 diameter was calculated. In cases where 1995 age-regressions included stand basal area as an independent variable, a second equation was developed to exclude basal area for the calculation of 1900 diameter. The current basal area may not necessarily be associated with 1900 conditions.

Two methods were used to calculate stump ages. Some stumps had field counts for ages, for others I had to estimate age at time of death through regressions. For the field counted stumps, a simple equation of the form

$$\text{AGE} = e^{\ln(\text{DIA})*k} \qquad \textit{eq. 7}$$

was used plugging in the field counted age and diameter

and solving for k, where

$$k = \ln(AGE) / \ln(DIA) \qquad \textit{eq. 8}$$

DIA=The Diameter of the stump
AGE=field count of stump.

Then 1900 age and diameter were calculated using

$$AGE1900 = AGE - (YEARLOGGED - 1900) \qquad \textit{eq. 9}$$

and

$$\ln(DIA1900) = [\,(\ln [AGE1900]\,) / k\,] \qquad \textit{eq. 10}$$

For stumps that did not have field counts I estimated the age at time of cutting using the age regressions developed for the live trees. The 1900 ages were estimated using equation 9 from above. These ages were then inserted into

$$DIA1900 = (C^{*}Elevation - AGE1900+Constant)/B. \qquad \textit{eq. 11}$$

where B and C are regression coefficients.

Snag time since death was estimated by assigning the decay classes from Arno et al (1993):

decay class	time since death
1	0-10 years
2	11-25 years
3	26+ years

The above description of classes correspond to diagrams (Appendix C) of Maser et al (1979). The midpoints of the above classes were used to assign a time since death for calculations. The 1900 diameters were then estimated in the same method as described for stumps without field counts.

Composition and Structure changes

Conifer species composition was calculated as a percentage of basal area. This was calculated for conifer species across all study areas, within each face, across all elevations, and within the three elevation ranges: 4500-5800, 5800-6800, and 6800-7500. Diameter distribution charts were produced to examine changes in stand structures within each species.

Plot classification

Cover types were defined by the order of conifer species dominance. Species dominance was defined by the each species' proportion of total stand basal area. I used a classification which identifies the two most dominant species. A species had to comprise at least 10% of the total stand basal area to be counted as a stand component. If only one species made up more than 10% of the stand basal area it was classified as a single species stand. Otherwise, stands were classified by two species combinations. A

transition matrix was produced to chart the successional pathways of these stands in the last century.

Relating change to environment and disturbance

I used fire types as a basis for relating change to environment. Additionally, a disturbance index was assigned to each plot. For plots that experienced logging the fire record was poor. Plots usually had disturbance information for either logging or fire, but seldom both.

A logging index was assigned to each plot based on the sum of stump basal area. A plot whose stumps represent less than 75 square feet per acre was given a low index, 75 to 150 square feet per acre was classified as medium and above 150 square feet per acre was considered high. The logging codes are not severity codes as a clearcut stand with less than 150 square feet basal area could have a low or medium index. A 'no logging' category listed those plots which had not been harvested. A fire severity classification of either 'stand replacement', 'mixed mortality', 'non-lethal' or 'unknown severity' was assigned to most recent fire. The definition of stand replacement for my purposes was a fire in which there were no survivors. The unknown severity usually encompassed plots which there was no evidence of mortality or survivors from a fire event. For example a plot which had not seen fire for 200 years may have had survivors in the last disturbance event but those trees may now be well decayed and gone. The fire severities classified as 'unknown' generally represented stands not burned for a long time.

RESULTS

Describing forests in two time periods

Tree age-diameter relationships

There were significant relationships between diameter and age for trees of all species. All species except for lodgepole pine and subalpine fir showed normal distributions and equal variances. The correlation statistics between age and all combinations of the independent continuous variables are listed in Appendix D. The variables used were not the same for all species (Table 1). Only one species, ponderosa pine, had sufficient variance explained by fire type to justify stratification. The exact age of trees on all plots would have been extremely hard to estimate in the field (Fig. 4 and Fig. 5). Regression statistics suggest that because of high variability, these equations will give more objective, yet reasonable estimates of tree ages than if done manually or from qualitative field estimates.

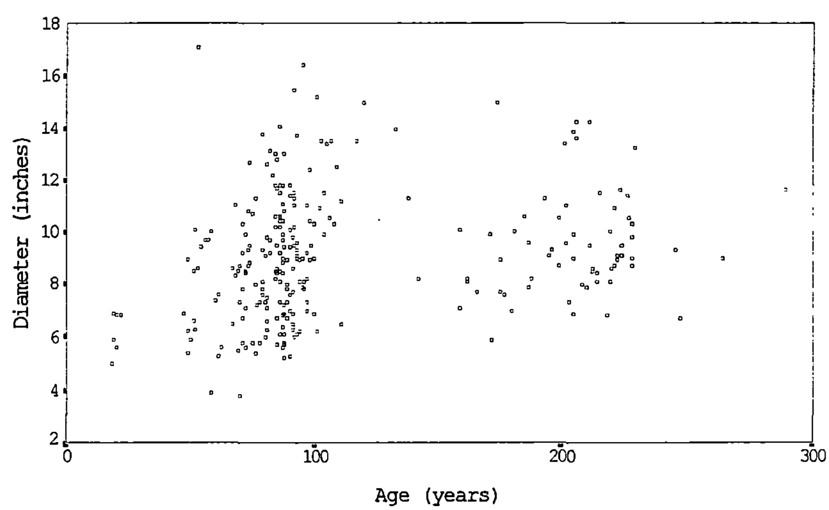

FIG 4. Age-diameter relationship of lodgepole pine. A bimodal distribution of ages appears to have resulted from episodic disturbance.

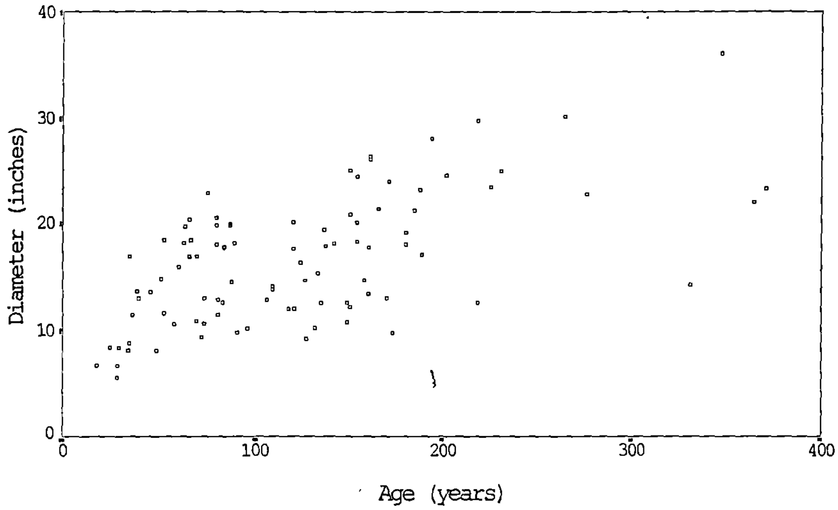

FIG 5. Age-diameter relationship of ponderosa pine.

TABLE 1. Variables used for each species in age regressions.

Species	Variables used in age regressions				grouped by :
	Diameter	Elevation	Stages Classification	stand basal area	
Ponderosa pine	X	X			Fire group
Douglas-fir	X	X			
Western larch	X	X			
Lodgepole pine	X				disturbance
Engelmann spruce	X	X			
Subalpine fir	X				
Whitebark pine	X			X	

In all species except Douglas-fir, diameter was the most powerful linear correlate to age (Appendix D). Even though the elevation-age relationship gave a better R^2 than dbh-age regressions for Douglas fir, the dbh-age R^2 still exceeded those of lodgepole pine, spruce and subalpine fir. However the variance (MSE) for Douglas-fir was nearly twice that of spruce and subalpine fir. All the models were improved dramatically by the inclusion of a second variable. Improvements by using three and four variables were negligible to non-existent.

As can be seen in Fig. 4 and Fig. 6, the linear relationships for lodgepole pine and subalpine fir were nearly unrecognizable. For these species, different approaches were needed (see methods). The fire age data was broken into two classes for trees greater than and less than 150 years old. While the lodgepole equations did have R^2 values near zero, the mean squared errors were quite low (Table 2).

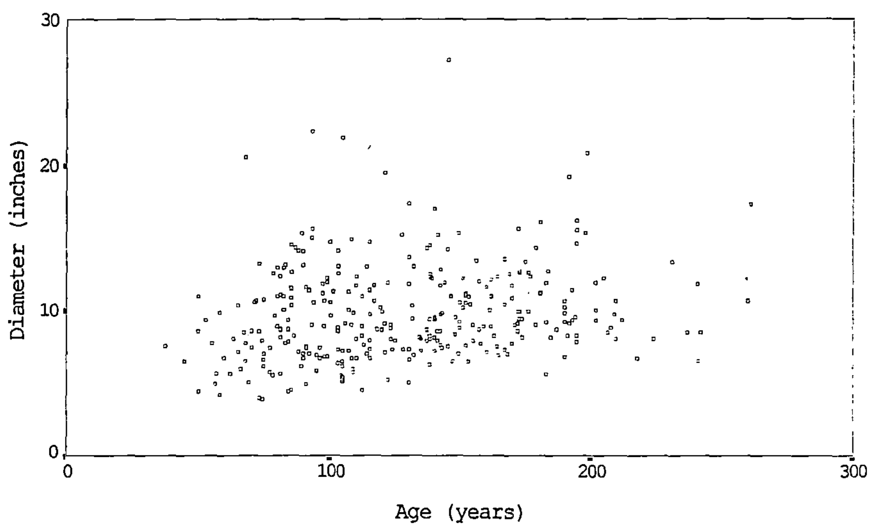

FIG 6. Age-diameter relationship of subalpine fir.

The final forms of the regressions used and their associated statistics are given in Table 2.

TABLE 2. Regression equations and statistics for age predictors. Transformations are log base=e, DBH measured in inches.

Species	**equation**	**SE**	**R^2**	**n**
Ponderosa pine	log(age) = log(dbh) (1.2518) + 1.2644	**0.50**	**.50**	**51**
fire group 6				
Ponderosa pine	log(age) = log(dbh) (1.1512) + elev (0.0004) - 0.3972	**0.48**	**0.48**	**109**
all other fire groups				
Douglas-fir	log(age) = log(dbh) (0.6477) + elev (0.0005) + 0.3680	**0.39**	**.54**	**368**
Western larch	log(age) = log(dbh) (1.0228) + elev (0.0003) - 0.2381	**0.43**	**.48**	**70**
Lodgepole pine				
<150 years and				
> 6 inches	log(age) = log(dbh) (0.3882) + 3.5485	**0.29**	**.12**	**220**
< 6 inches	age = dbh (11.5)	-	-	
Lodgepole pine				
>150 years and				
> 6 inches	log(age) = log(dbh) (0.1250) + 5.0594	**0.14**	**.04**	**77**
< 6 inches	age = dbh (32.8)	-	-	
Engelmann spruce	log(age) = log(dbh) (0.5898) + elev (0.0003) + 1.2976	**0.35**	**.29**	**61**
Whitebark pine	log(age) = log(dbh) (0.8010) + ba (0.0020) + 3.1885	**0.31**	**.56**	**59**

Regressions to construct 1900 conditions

Because of poor relationships between tree size, site characteristics and tree age for lodgepole pine and subalpine fir, regressions were developed for radial growth based on tree ring analysis. It was expected that radial growth should be related to diameter because of suppression of smaller trees due to shade intolerance in the case of lodgepole pine and dense canopies for subalpine fir. The equations for radial growth are given in table 3. There was a significant relationship between the age of subalpine fir and the distance from the cambium to the ca. 1900 tree rings as measured on an increment core.

TABLE 3. Radial growth equations for lodgepole pine and subalpine fir.

Species	Equation	MSE	R^2	n
lodgepole pine <150 years	rg = coredbh (0.2931) + 0.8364	**0.50**	**0.24**	
lodgepole pine >150 years	rg = coredbh (0.2238) + 0.0937	**1.18**	**0.15**	**102**
subalpine fir	rg = d (-.048943) + 15.2582	**2.53**	**0.31**	**88**

where,
rg = radial growth in centimeters since 1900
coredbh = tree core diameter at breast height
d = distance from cambium to 1900 tree ring

Describing changes in the forest

Species Composition

Reconstruction of 1900 stand conditions from these stand data suggests that there has been a profound change in conifer species composition across all landscapes between 1900 and 1995 (Fig. 7a). All fire tolerant conifer species except for lodgepole pine showed a decrease in abundance. Douglas-fir, Engelmann spruce and subalpine fir all showed increases in their relative proportion of total landscape basal area. Figure 7a provides very rough depiction of the changes that have taken place. The elevational ranges and forest types represented by this figure allow only general interpretations. Finer scale changes require examination of the individual ridge faces and forest zones. It should be recognized that not only did the relative percentage of species change but the total basal area increased on all study areas over the last 100 years, and by orders of magnitude on most sites (Fig. 8).

Changes in species composition varied widely by elevation zone and study area (7b, 7c and 7d). In the lowest elevation zone, the most pronounced change in composition is in the increase Douglas-fir. The relative percentage of this species increased over two times its 1900 value (figure 7b). Ponderosa pine and western larch were reduced by 25% and 14% respectively. From 5800 to 6800 feet the changes are more subtle (figure 7c). No species except for western larch experiences a change in percentage greater than 6%. Western larch has been reduced to one quarter of its 1900 basal area. A similar decline is found in whitebark pine from 6800 to 7500 feet elevation (figure 7d). Interestingly lodgepole appears to increase its percentage between the time

periods.

Changes in low elevation conifers are somewhat similar between the two sampled 4500-5800 foot elevation zones but their magnitudes are quite different (Fig. 7e, 7f). Western larch is not even a stand component at Cow Creek in 1995 and only makes up 2% in 1900, yet at St. Joe it makes up 51% and 25% of the 1900 and 1995 basal area respectively. Both study areas show a sizable increase in the percentage of Douglas-fir. The reduction in ponderosa pine on Cow Creek is 42% and only 10% at St. Joe.

The middle elevation zone of Sweeney face showed patterns inconsistent with the same elevation range of the other two areas (Figs. 7g-7i). Here Douglas-fir decreased substantially and lodgepole pine increased 35%. Ponderosa pine, and whitebark pine both decreased across all three areas. Again, Cow Creek was devoid of any western larch at this elevation range and St. Joe had a dramatic decrease in this species. The only unfailing pattern consistent across all three areas in this elevation range was an increase in subalpine fir.

The upper elevation whitebark pine forests above 6900 feet had similar increases in subalpine fir (Figs. 7j, 7k). Whitebark pine had huge decreases in its relative percentage of basal area. Lodgepole pine had incongruous changes between the two areas, increasing by a massive 39% on St. Joe and decreasing by 13% on Cow Creek. Engelmann spruce was most dominant in the whitebark pine zone of St. Joe and maintained its percentage of abundance here throughout the last century. At Cow Creek, Engelmann spruce was undetectable in 1900 and made up only 1% of total basal area in 1995.

Cover Types

There have been drastic changes in cover types in the last century (Table 4, attached). A Chi-squared test showed there was a significant change in cover types across 216 plots on all study areas between 1900 and 1995 (X^2=88.86, p<0.005, df=38). Only 36 of 216 plots remained the same cover type in this time period. Changes were significant on each individual face in addition to all faces combined. Chi-square tests for each face consistently showed with greater than 99.5% confidence that there has been a deviation from expected values.

Some cover types present in 1900 were non-existent in 1995 and vice versa. The most striking pattern in changes in cover types is the complete loss of many whitebark forests. It should be noted that whitebark pine is a timberline species and that had more plots been sampled at higher elevations more whitebark types and plots would have existed in 1995. However, this data does represent a loss of whitebark pine from its lower elevation range where it is especially important aas a food source (nut-like seeds) for wildlife (Arno and Hoff 1989). The development of new cover types not found in 1900, in 12 out of 14 cases contained late successional, shade tolerant, fire-intolerant subalpine fir or grand fir.

The total frequencies across all study areas shows an increase in shade tolerant firs and a decrease in shade intolerant, fire resistant pines. Pure ponderosa pine, western larch and whitebark pine cover types all decreased by at least 75% of their 1900 values. All Douglas-fir and subalpine fir dominated cover types maintained or showed an increase in

their frequencies. Out of the 9 cover types containing a whitebark pine component in 1900 only 2 remained in 1995.

Fire History

The extent of fire events varied across time and between study areas (Fig. 9). Only in one fire year (1889) did fire affect all of the study areas. This was also the year that the greatest number of plots were affected by fire. There is an inverse relationship between the extent of fire and the number of fire occurrences on all faces. The areas experiencing more extensive fires had fewer fire events. For example, Cow Creek had a fire in 1770 that covered near 90% of the plots in that study area, only 3 other occurrences of fire are found on this ridge face. On the other hand, Sweeney face didn't have one fire that covered over 60% of its plots and there were 8 other occurrences of fires. St. Joe fell in the middle of these having a fire covering 70% of its plots and 6 other occurrences of fire.

There was a difference in the fire severity between elevational zones (figure 10). The three elevation ranges in Fig 10 represent a transition from the lodgepole zone to the lodgepole/whitebark pine types. I found a general change from non-lethal and stand replacement to mixed mortality fire events along this elevational gradient. Note the elevations between 5800 and 6900 feet represent 3 study sites while those above 6900 represent only 2. Thus, the total frequency of events is misleading, however, the frequencies as a percentage of the total within zones provides a clear portrayal of these changes. There were 45 plots affected by fire events that could not be placed into a

severity category. Most of these were old fires and evidence of their effects had deteriorated or been consumed in subsequent fires.

Changes in stand structures

The diameter distribution of ponderosa pine in the lower forest zone has changed significantly over the last century (Fig. 11a). The distribution of individuals in diameter classes, has changed from being relatively flat to more a of reverse J-shape distribution. So although in 1900 there were fewer individuals, a larger proportion of those were bigger trees.

The diameter distribution for Douglas-fir at this same elevation shows a different pattern (Fig 11b.). The Douglas-fir alive today are much larger than they were at the turn of the century. There has been a dramatic increase in the number of smaller individuals. In the next higher elevation zone, there were no decreases in any of the diameter-classes (Fig. 11c). It is also apparent that although the total number of Douglas-fir have changed in this zone, the general diameter distribution has not been drastically changed. Although, there are more larger individuals now. A similar pattern has occurred in lodgepole pine in the 6900-7500 foot elevation zone (Fig. 11d).

Relationship of species composition change to climate (as represented by fire groups) and disturbance

The environment and level of logging on sites had an effect on ponderosa pine median basal area change (Fig 12a). Within fire group 6, ponderosa pine interestingly

changed the least in stands with no logging or with the highest level of logging. Figure 12b shows between logging levels there was a difference in medians in moist Douglas-fir forest types (fire group 6) but not in warm, dry Douglas-fir types (fire group 4). There was insufficient representation in the other fire groups to make inferences. The overall effect of environment on change is questionable without further statistical analysis. The decrease in ponderosa pine was generally associated with an increase in Douglas-fir (Figs. 12a-b).

Moisture availability (as suggested by fire groups) appeared to have an effect on the amount of change in Douglas-fir. Unlogged plots in dry sites (fire group 4) showed a dramatic difference from non-logged stands in moist sites (fire groups 6, 7, 8 and 9) and experienced a greater increase in Douglas-fir. The median change of low level logged stands in fire group 4 was much smaller than in the other groups. Within fire group six the median change decreases with higher levels of logging, but plots with no logging had almost no change.

In the upper elevations where fire was the dominant disturbance, there appeared to be little effect of moisture availability on the change in lodgepole pine and subalpine fir (Figs. 13a-b). Changes in lodgepole pine and subalpine fir appear to be related to the severity of the most recently occurring fire (Figs. 13a-b). Thirteen out of the 16 lodgepole pine stands classified as 'unknown severity' had not burned since before 1800. Likewise, 14 out of the 16 'unknown severity' subalpine fir stands had not burned since 1800. Where fire severity was known, the differences between them followed the same pattern for all fire types in both of these species. Generally, the percentage change of

subalpine fir increased with decreasing fire severity. In subalpine fir the highest increases for fire groups 7 and 9 was in unknown severities and for fire group 8 in mixed mortality fires. Whitebark pine showed the lowest level of decline in forests last experiencing stand replacement fires (Fig. 13c). For whitebark pine in unknown severity categories there appeared to be a significant difference in percentage change due to fire group.

IMPLICATIONS FOR MANAGEMENT

Striking changes have come to landscape disturbances on the Bitterroot Front in the last 100 years, especially at the lower and extreme upper elevations. The resulting shift in vegetation has been from forest types dominated by fire tolerant species to fire intolerant-late succession species. Restorative management should be designed with a sensitivity to the differences that have occurred by elevation zone, historic disturbance and environmental conditions. This study provides a quantitative depiction of historic forest conditions based on a systematic sample design throughout the major forested types of a mountain range face. It offers the reality of field data and a comparison of two points in time to relate to landscape dynamics. The consideration of this data for management suggests that ecological processes need restoration at a broad scale if historic ecosystem function is the management goal. This data will also help provide managers with expected vegetation shifts under differing management scenarios.

Large decreases in ponderosa pine are consistent with many historical descriptions and studies (Arno et al 1997, Arno et al 1995, Habeck 1990, Losensky 1995). The differences between study areas underlines the importance of environmental sensitivity to restoration. It is generally assumed that low elevation forested sites were formerly dominated by ponderosa pine, however, western larch made up the largest proportion of basal area on St. Joe face in 1900. On Cow Creek face, near the southern limits of western larch, ponderosa pine made up the largest proportion of landscape basal area. These data depict landscapes abundant with both larch and/or ponderosa pine at similar elevations, depending on localized moisture and temperature conditions. Regardless of the dominant historic species, Douglas-fir is now taking over the growing space in both sites. Restoration of this elevation zone and the ecological processes

therein should be aimed at restoring species compositions, stand structures and ecosystem function. The restoration of past structures and function in many cases require a silvicultural treatment in conjunction with prescribed burning. However even after initial treatment the desired structures cannot be maintained without the use of frequent fire as this is a key driving force behind functioning Rocky Mountain forests. Further describing the spatial structure of these lower elevation forest types would be valuable information to managers aiming at landscape restoration.

My overall findings in the lodgepole pine and whitebark zones generally agree with Arno et al. (1993) who showed a decrease in lodgepole pine and whitebark forest types. Two of my study areas showed an increase in lodgepole pine. This is likely due to different disturbance histories, as their study area lacked the occurrence of widespread major stand replacing events around the turn of the century. The one site I had in which lodgepole declined hadn't undergone the extent of burning the other two had. All sites showed large amounts of whitebark pine loss.

The loss of whitebark pine was lower on sites that had experienced stand replacement versus mixed mortality fires. Thus vegetation manipulation which creates openings may be the best bet in perpetuating this species and bringing it back to higher levels. There has are proposals for reintroducing the grizzly bear into the Selway-Bitterroot Wilderness. Grizzly bears utilize whitebark cones at certain times of the year as a critical source of protein and lipids. A decline in whitebark pine populations will likely diminish grizzly bear habitat. Being on the edge of the Selway-Bitterroot Wilderness, management of these whitebark pine zones will require a sensitivity to this issue.

This study show a landscape in transition. Natural forces which once drove these

ecosystems are being removed and replaced with anthropogenic disturbance. We must make choices about the manner in which we interact with and become part of the ecosystem. Many of the choices we have made in the past have resulted in undesirable conditions for recreation, fire danger and wildlife habitat. It is crucial to understand what causes changes in the landscape and where this change is occurring. The most important result of this study to future planning is the description of how an array of stands have responded to different types and levels of disturbance. The type of disturbance, its severity and where it occurs will each affect the response a forest has. This information is critical to meeting long-term management goals and perpetuating the function of ecosystems into the future.

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Table 4. Number of plots in cover type by study area and year.

Cover type	St. Joe		Cow Creek		Sweeny		Total	
	1900	1995	1900	1995	1900	1995	1900	1995
PP	7	1	15	4			22	5
PP-DF	2	4	10	9	3	1	15	14
PP-L	3						3	
PP-GF				1				1
WL-PP	3	1			1	1	4	2
WL-DF	10	7					10	7
WL	7	2	1		2		10	2
WL-LP	4						4	
WL-WB					1		1	
WL-SAF	1	2					1	2
LP-DF	1	4	4	1	2	3	7	8
LP-L	1	2				1	1	3
LP	5	8	5			2	10	10
LP-ES	2	1					2	1
LP-SAF	3	9	11	8		4	14	21
LP-WB			10				10	
WB	2		2				4	
WB-DF			2				2	
WB-LP	3		1				4	
WB-SAF	2		1	1			3	1
WB-ES	1						1	
DF	5	4	9	20	9	1	23	25
DF-PP	1	7	3	6	1	3	5	16
DF-L	3	6			4	3	7	9
DF-LP	2	3	1	2		5	3	10
DF-WB	1		2				3	
DF-SAF	3	1	5	14			8	15
DF-ES				1				1
DF-GF				1				1
ES	1		1				2	
ES-LP		1						1
ES-SAF	2	5					2	5
SAF	2	3		1	3	2	5	6
SAF-DF	4	7	6	7			10	14
SAF-L	4	4					4	4
SAF-LP	7	5	1	7	1	2	9	14
SAF-WB	3	2		6	1		4	8
SAF-ES		9		1				10
NF	3						3	
Total	98	98	90	90	28	28	216	216

FIGURE CAPTIONS

Figures 7a-k. Percentage of basal area by species. Note: Total basal area between 1900 and 1995 are quite different. Percentages are measures of abundance relative to total basal area. 7a) all study areas, all elevations, 7b) 4500-5800 feet elevation/all study areas, 7c) 5800-6900 feet elevation/ all study areas, 7d) 6900-7500 feet elevation/ all study areas, 7e) 4500-5800 feet elevation/St. Joe study site, 7f) 4500-5800 feet elevation/Cow Creek study site, 7g) 5800-6900 feet elevation/ St. Joe study site, 7h) 5800-6900 feet elevation/ Cow Creek study site, 7i) 5800 to 6900 feet elevation/ Sweeney study site, 7j) 6900-7500 feet elevation/ St. Joe study site, 7k) 6900-7500 feet elevation/Cow Creek study site.

Figure 8. Comparison of 1900 to 1995 average stand basal area, all study areas by elevation zone.

Figure 9. Percentage of plots above 5800 feet burned in a given year. Percentages of study sites total above one hundred percent because many plots had experienced more than one fire event.

Figure 10. Percentage of plots burned on each face classified by fire severity and elevation zone. Percentages of study sites exceed one hundred percent because many plots had experienced more than one fire event.

Figures 11a-d. A comparison of 1900 and 1995 diameter distribution by species and elevation zone. 11a) ponderosa pine between 4500-5800 feet. 11b) Douglas-fir between 4500-5800 feet. 11c) Douglas-fir between 5800-6800 feet. 11d) lodgepole pine between 6800-7500 feet.

Figures 12a-b. Proportion of total basal area change in ponderosa pine (12a) and Douglas-fir (12b) from 1900 to 1995 using 4 logging indices across different fire groups (Fischer and Bradley 1987). Fire group 4=warm, dry Douglas-fir habitat types, fire group 6= moist Douglas-fir habitat types, fire group 7= cool habitat types usually dominated by lodgepole pine, fire group 8= dry, lower subalpine habitat types, fire group 9= moist, lower subalpine habitat types, fire group 11= warm, moist grand fir, western redcedar, and western hemlock habitat types. Lines on bars represent median change, main box bodies represent the interquartile ranges, whiskers extend to largest observed values that are not outlier, circles represent values more than 1.5 box-lengths beyond 25th or 75th percentiles (outliers), asterisks represent values more than 3 box-lengths beyond 25th or 75th percentiles (extremes). Sample sizes are given just below x-axis. Note: Logging indices are not logging severity codes.

Figures 13a-c. Proportion of total basal area change in lodgepole pine (13a), subalpine fir (13b) and whitebark pine (13c) from 1900 to 1995 using 4 fire severity codes for most recent fire event. Differences between severity is displayed by fire group (Fischer and Bradley 1987). Fire group 6= moist Douglas-fir habitat types, fire group 7= cool habitat types usually dominated by lodgepole pine, fire group 8= dry, lower subalpine habitat types and fire group 9= moist, lower subalpine habitat types. Lines on bars represent median change, main box bodies represent the interquartile ranges, whiskers extend to largest observed values that are not outlier, circles represent values more than 1.5 box-lengths beyond 25th or 75th percentiles (outliers), asterisks represent values more than 3 box-lengths beyond 25th or 75th percentiles (extremes). Sample sizes are given just below x-axis.

Percentage of basal area by species

4500-7500 feet, all study areas

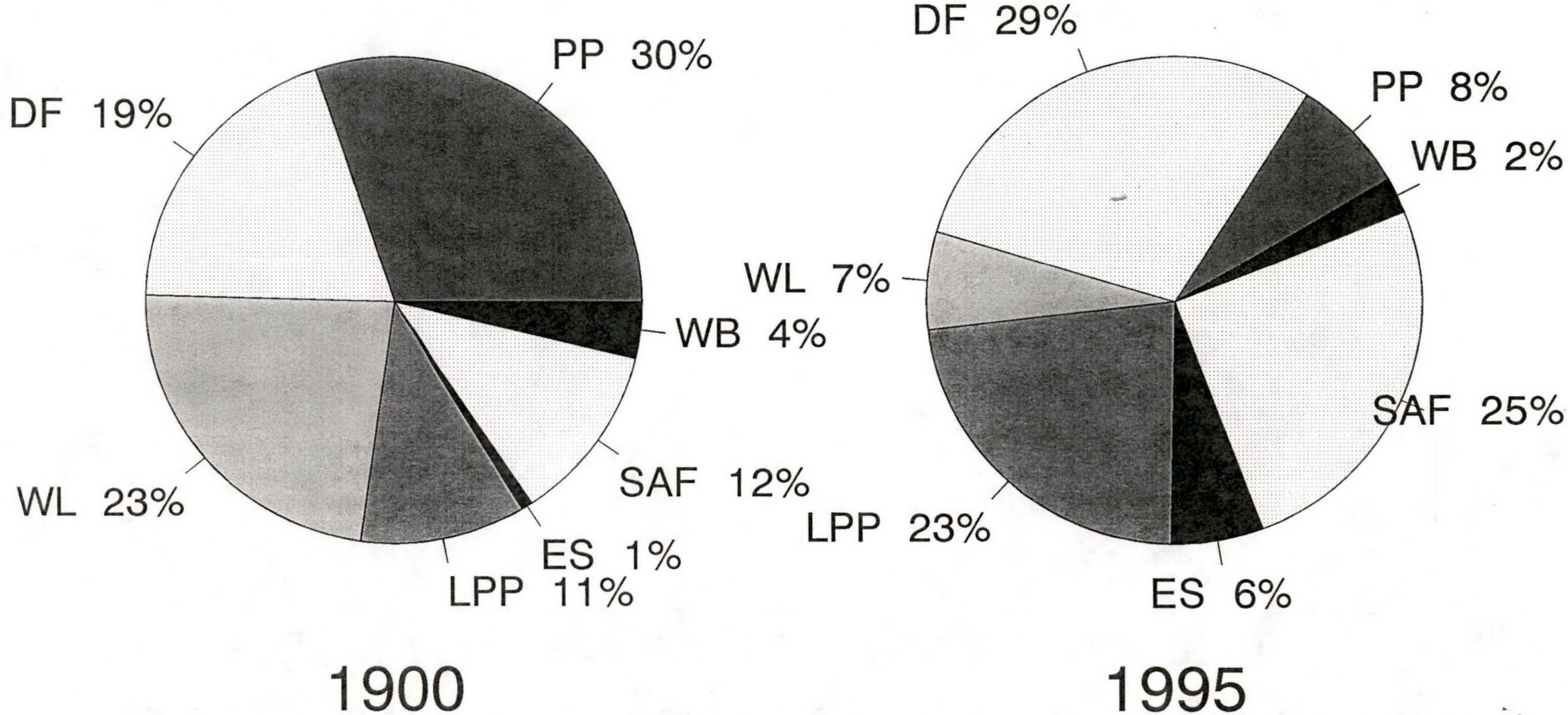


Figure 7a

Percent of basal area by species

All study areas 4500 to 5800 feet elevation

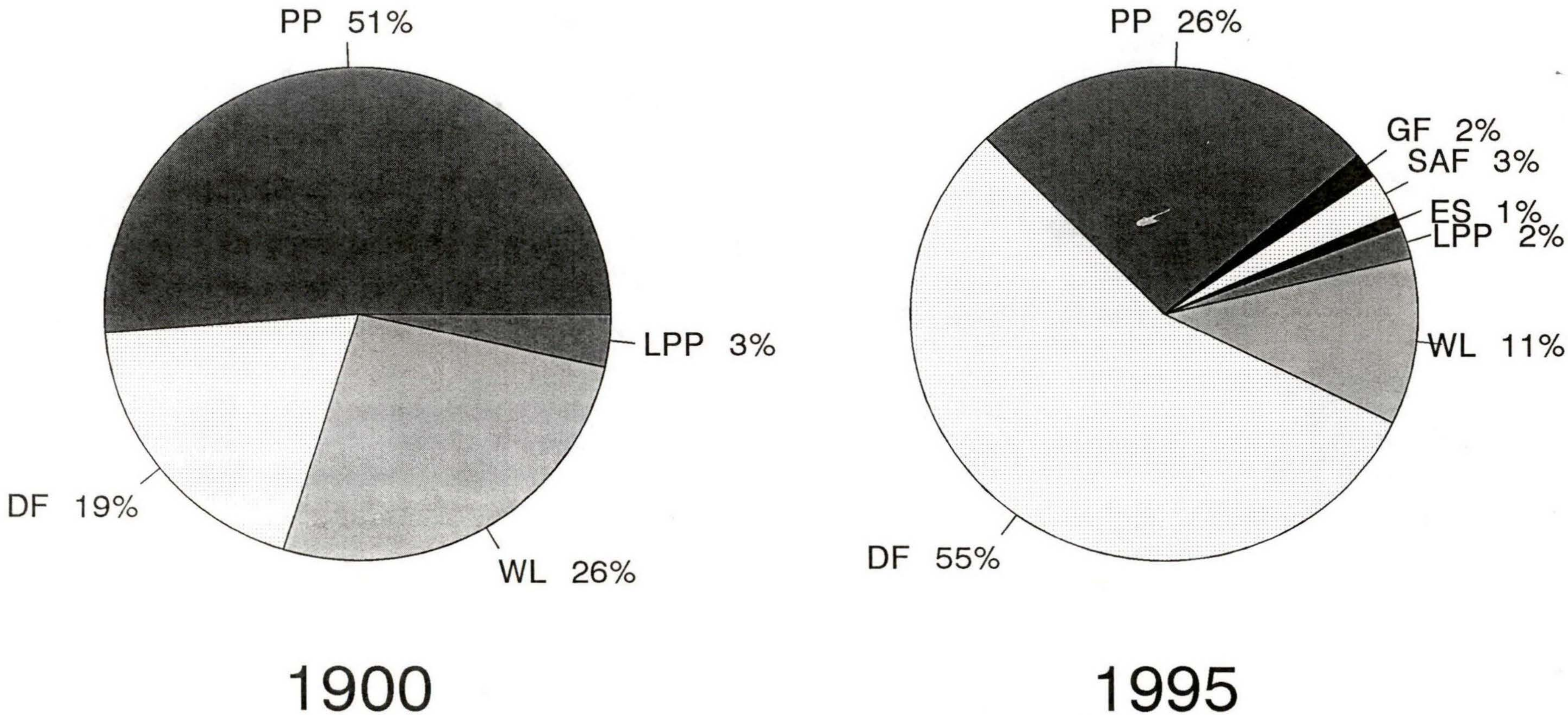


Figure 7b

Percent of basal area by species

All study areas 5800 to 6900 feet elevation

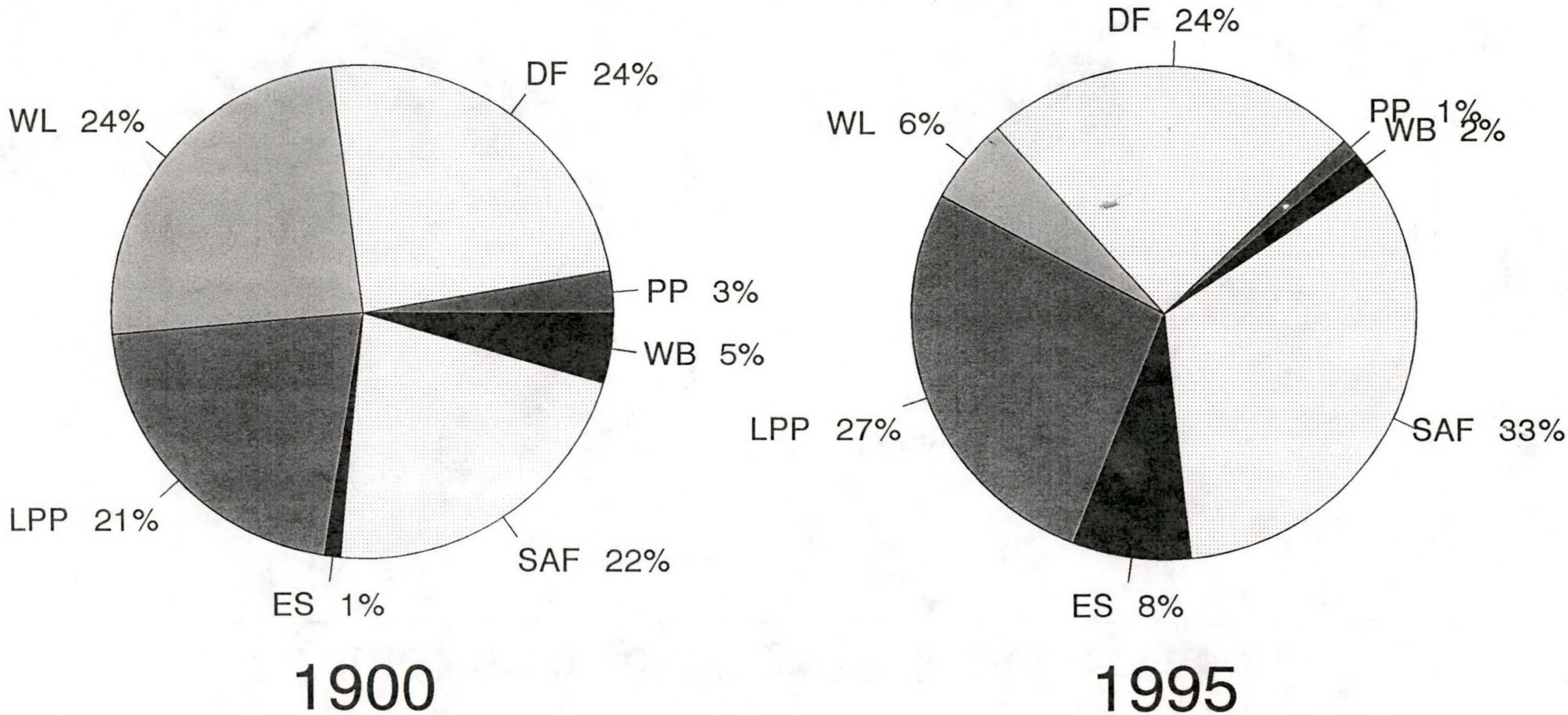


Figure 7c

Percent of basal area by species

All study areas 6900 to 7500 feet elevation

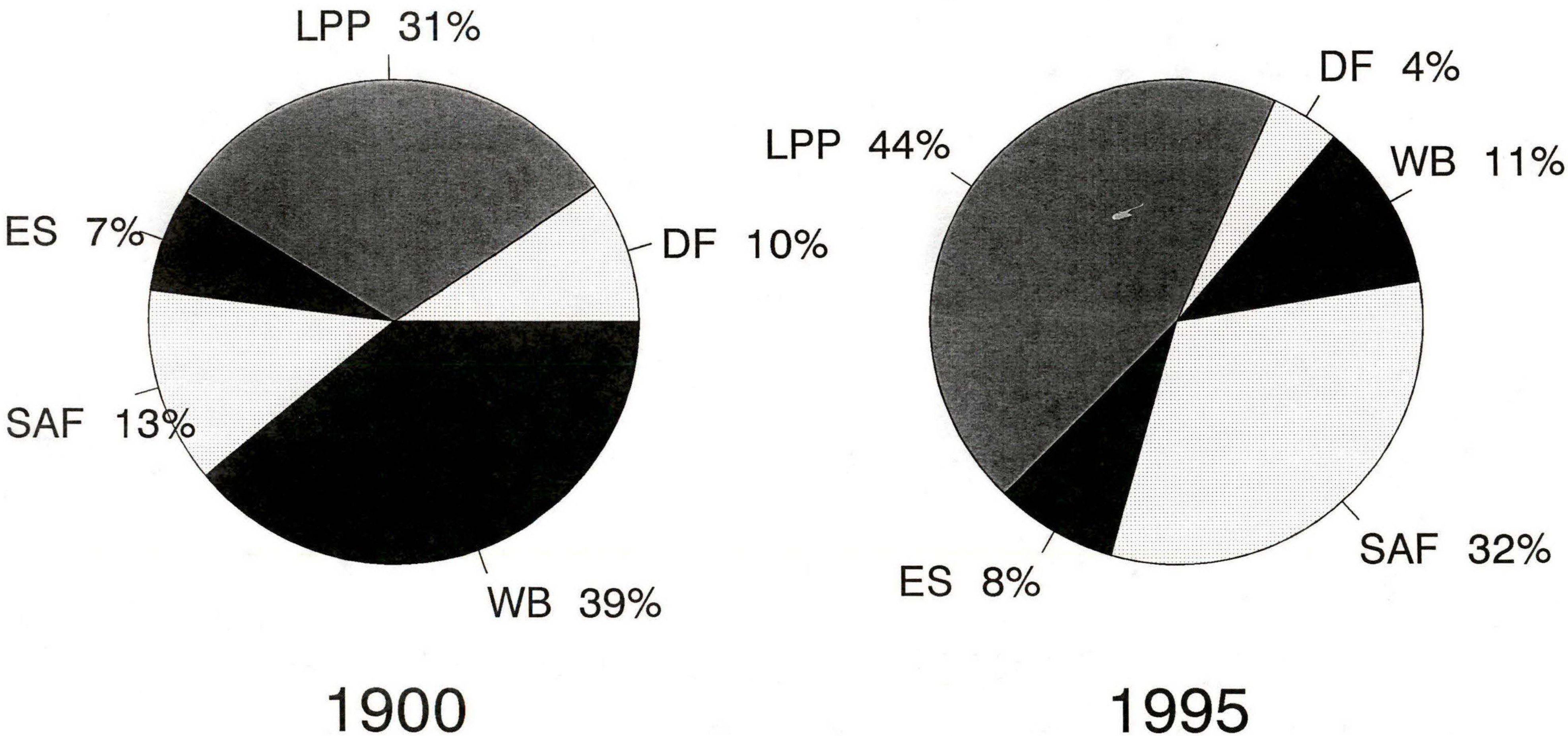


Figure 7d

Percent of basal area by species

St. Joe, 4500 to 5800 feet elevation

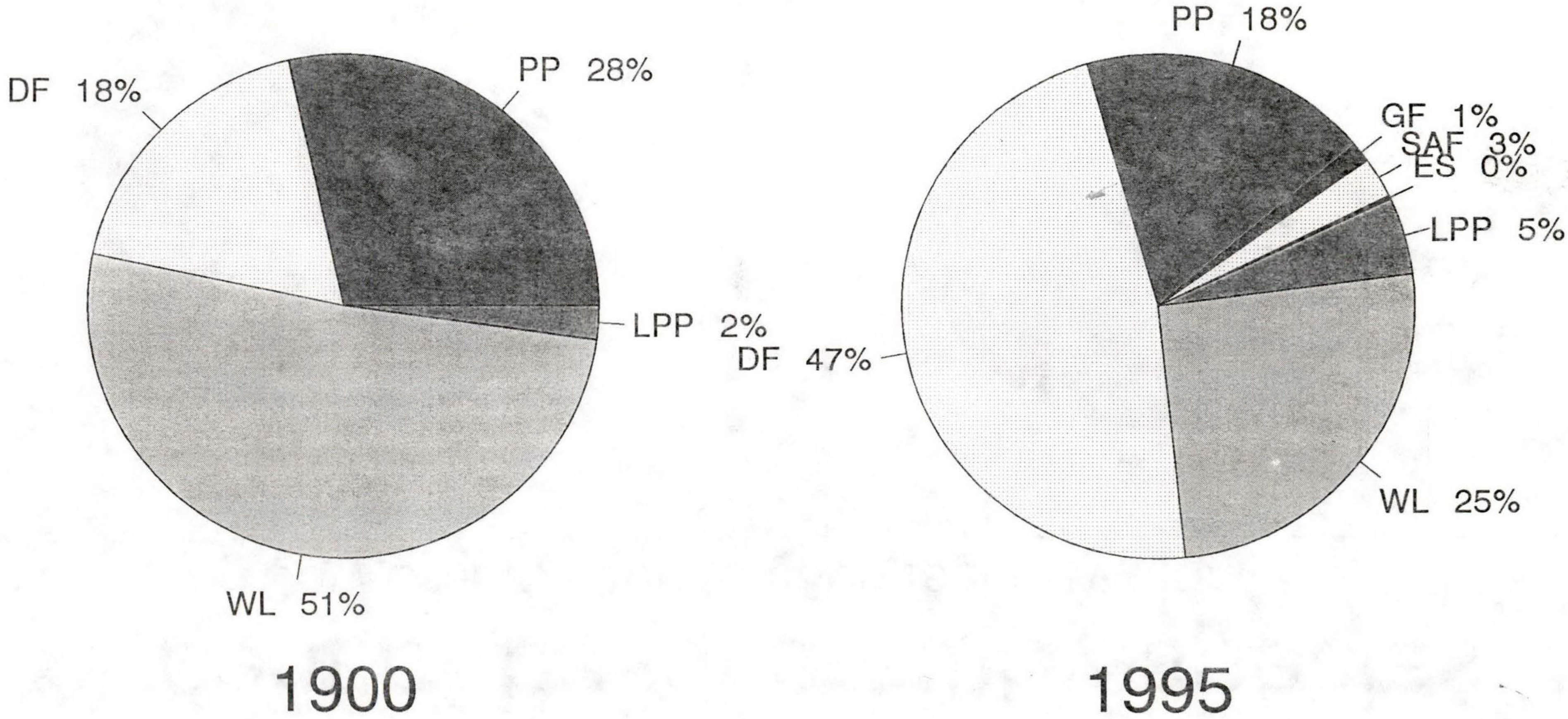


Figure 7e

Percent of basal area by species

Cow Creek, 4500 to 5800 feet elevation

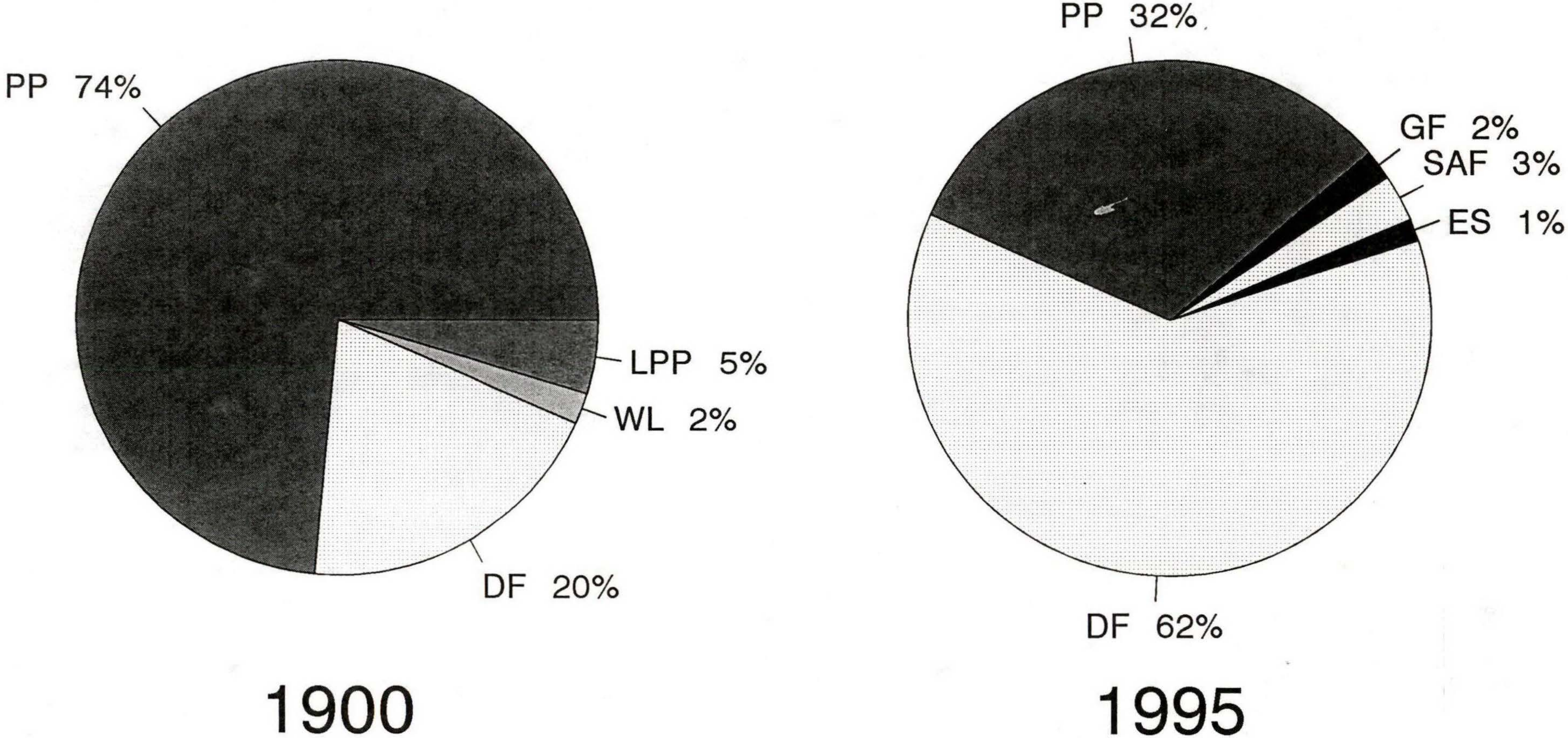


Figure 7f

Percent of basal area by species

St. Joe, 5800 to 6900 feet elevation

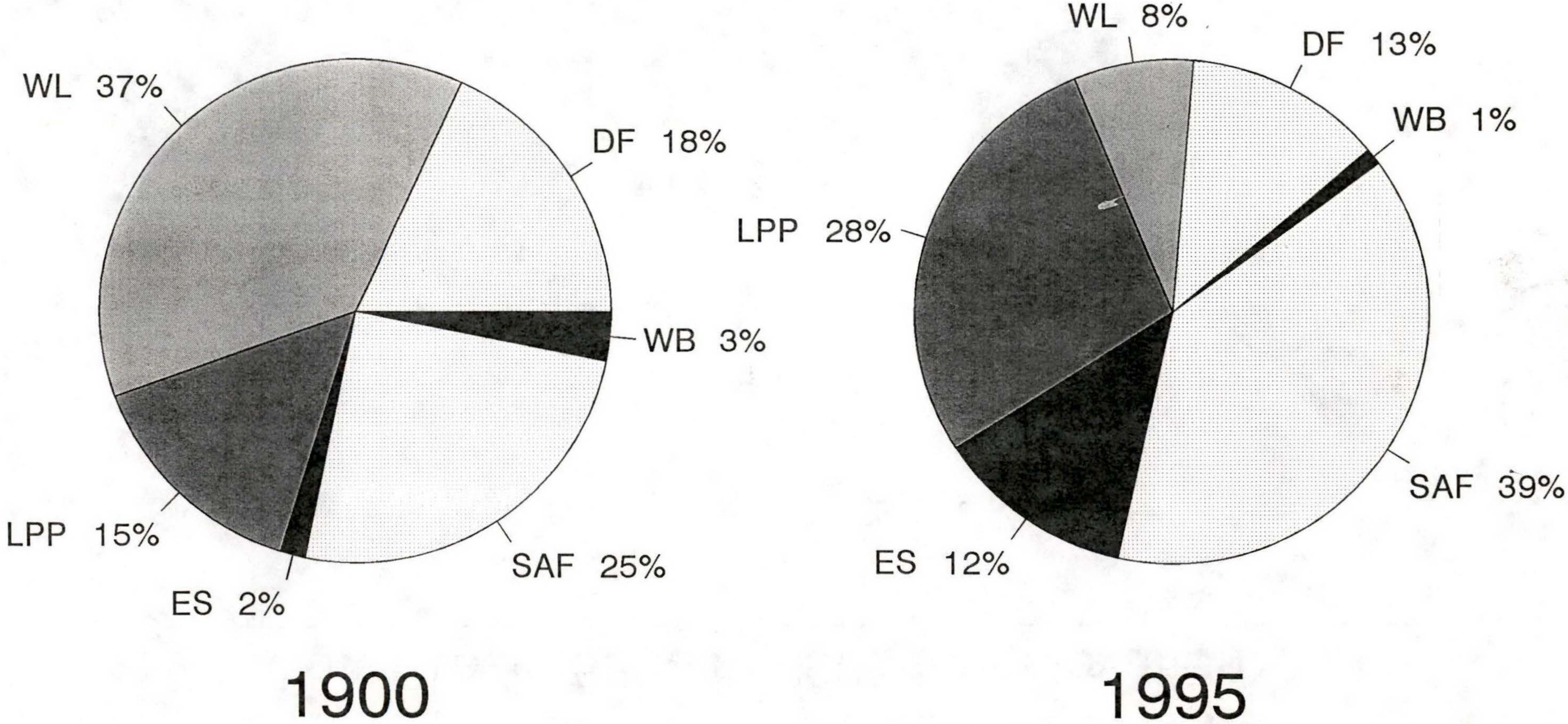


Figure 7g

Percent of basal area by species

Cow Creek, 5800 to 6900 feet elevation

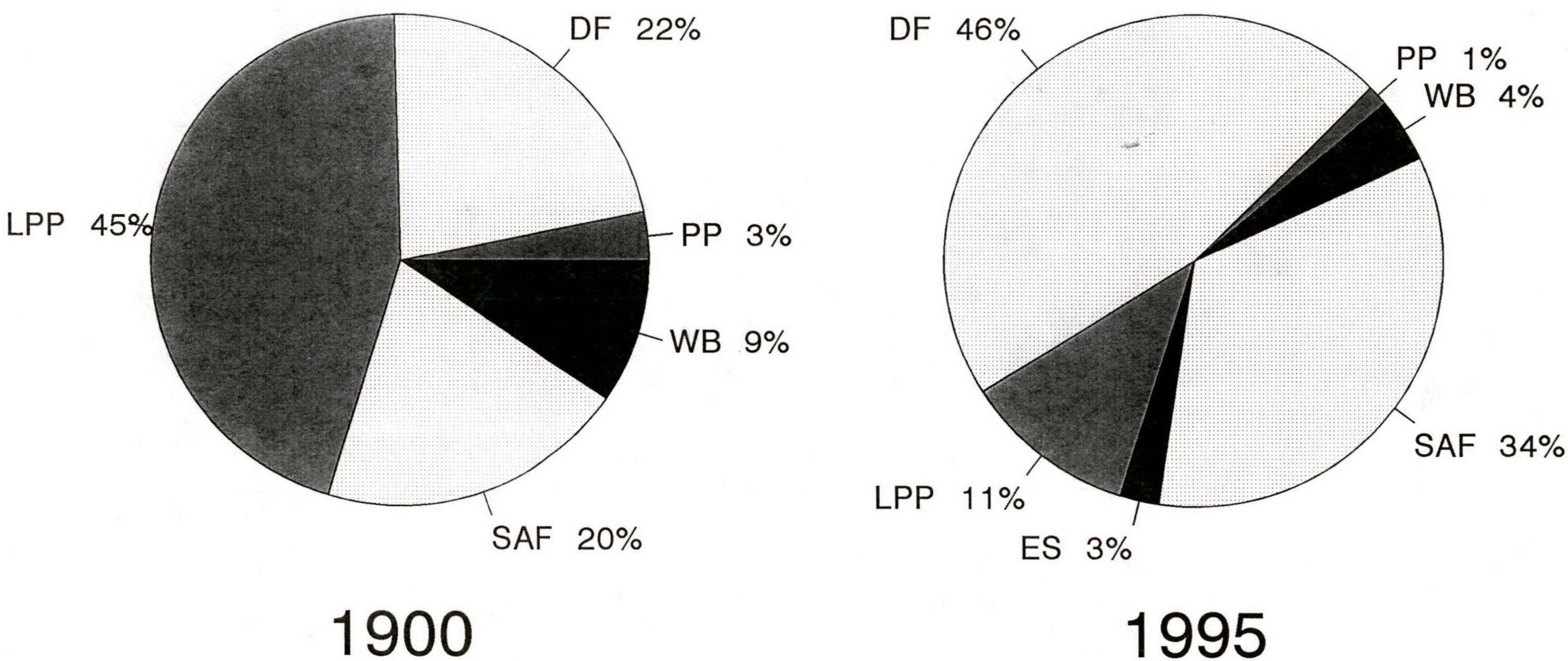


Figure 7h

Percent of basal area by species

Sweeney Creek, 5800 to 6900 feet elevation

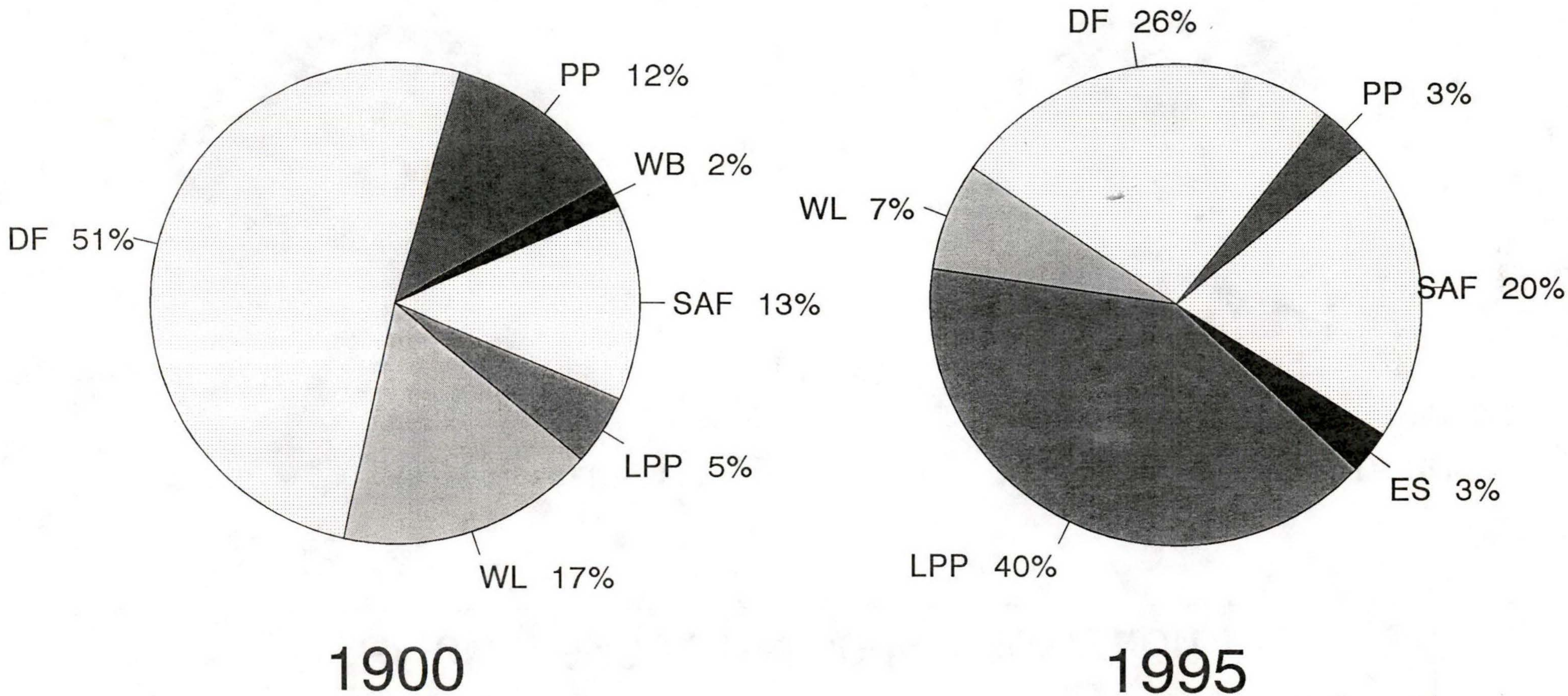
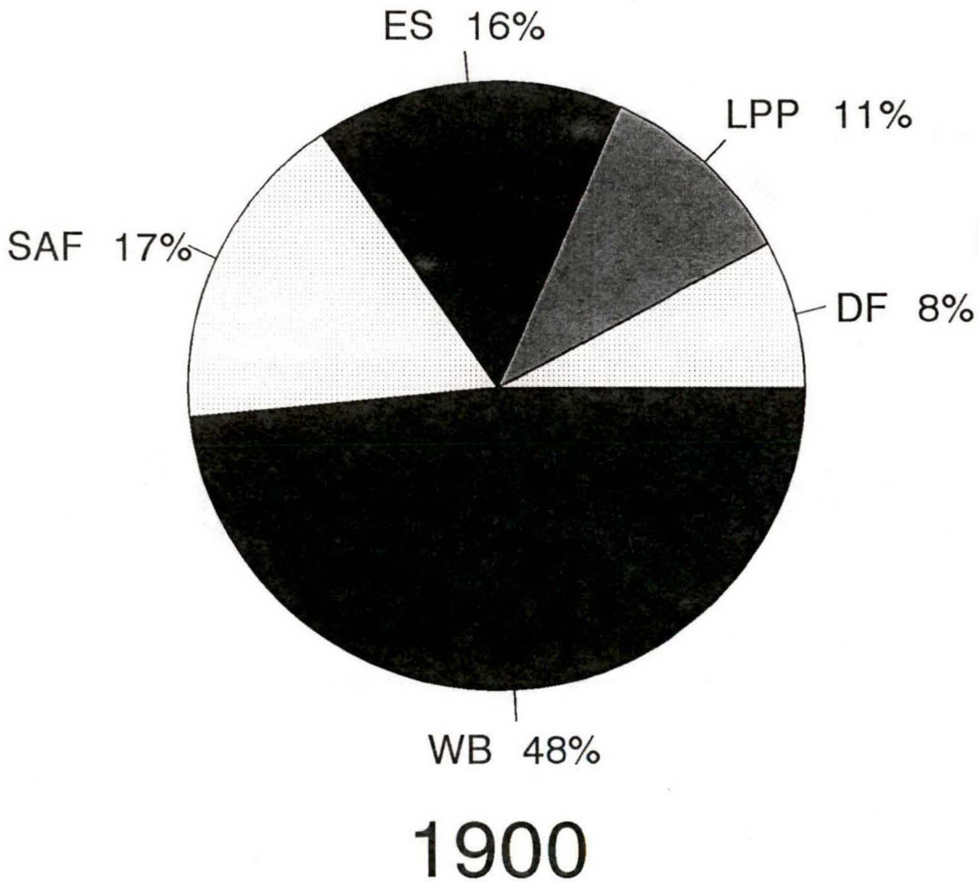


Figure 7i

Percent of basal area by species

St. Joe, 6900 to 7500 feet elevation



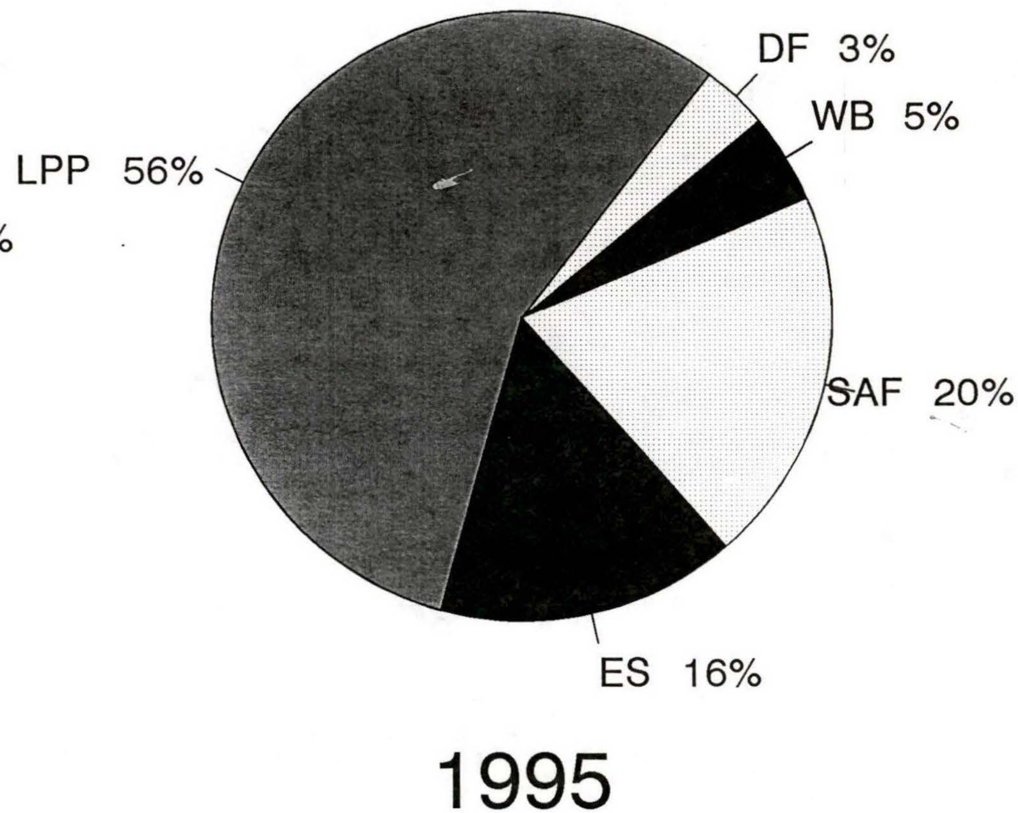


Figure 7j

Percent of basal area by species

Cow Creek, 6900 to 7500 feet elevation

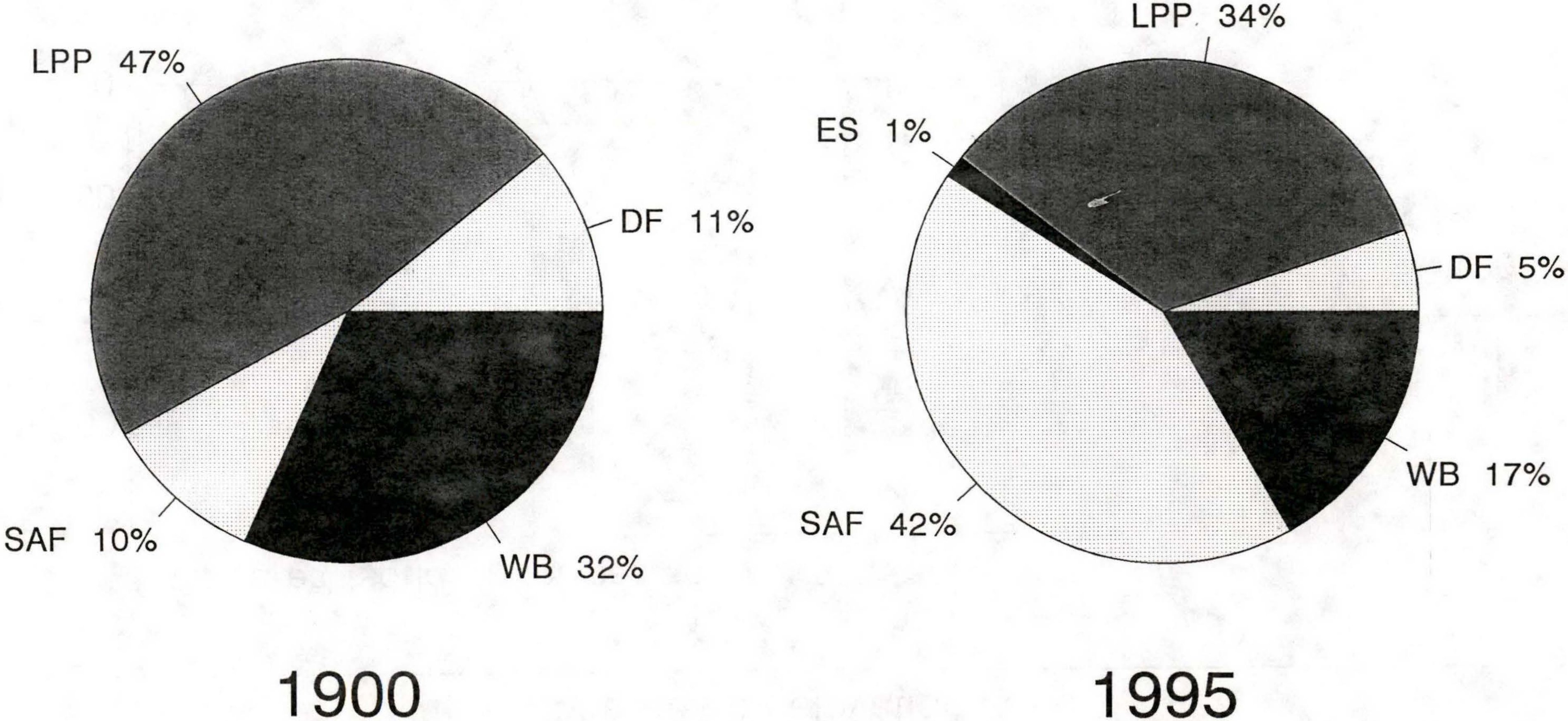


Figure 7k

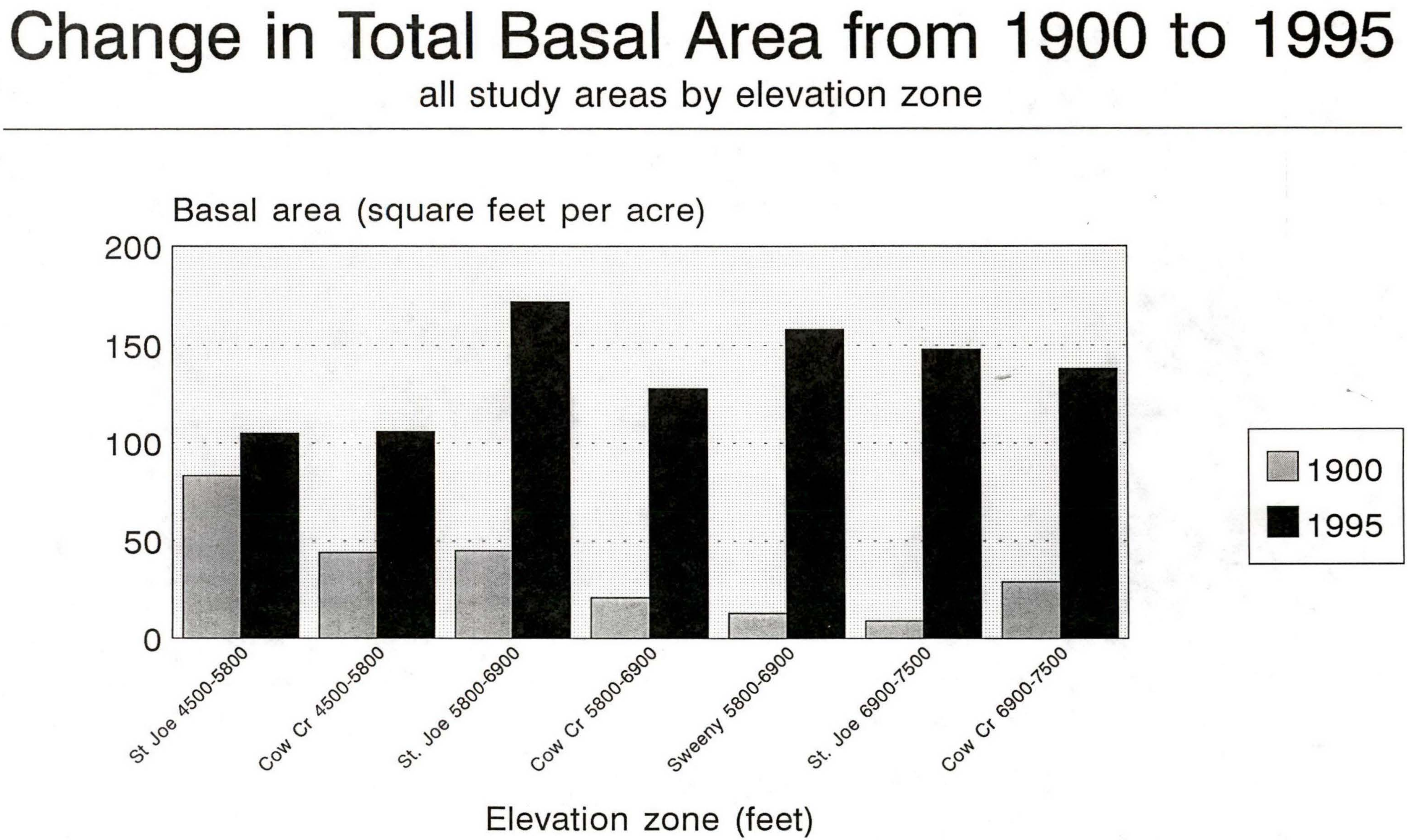
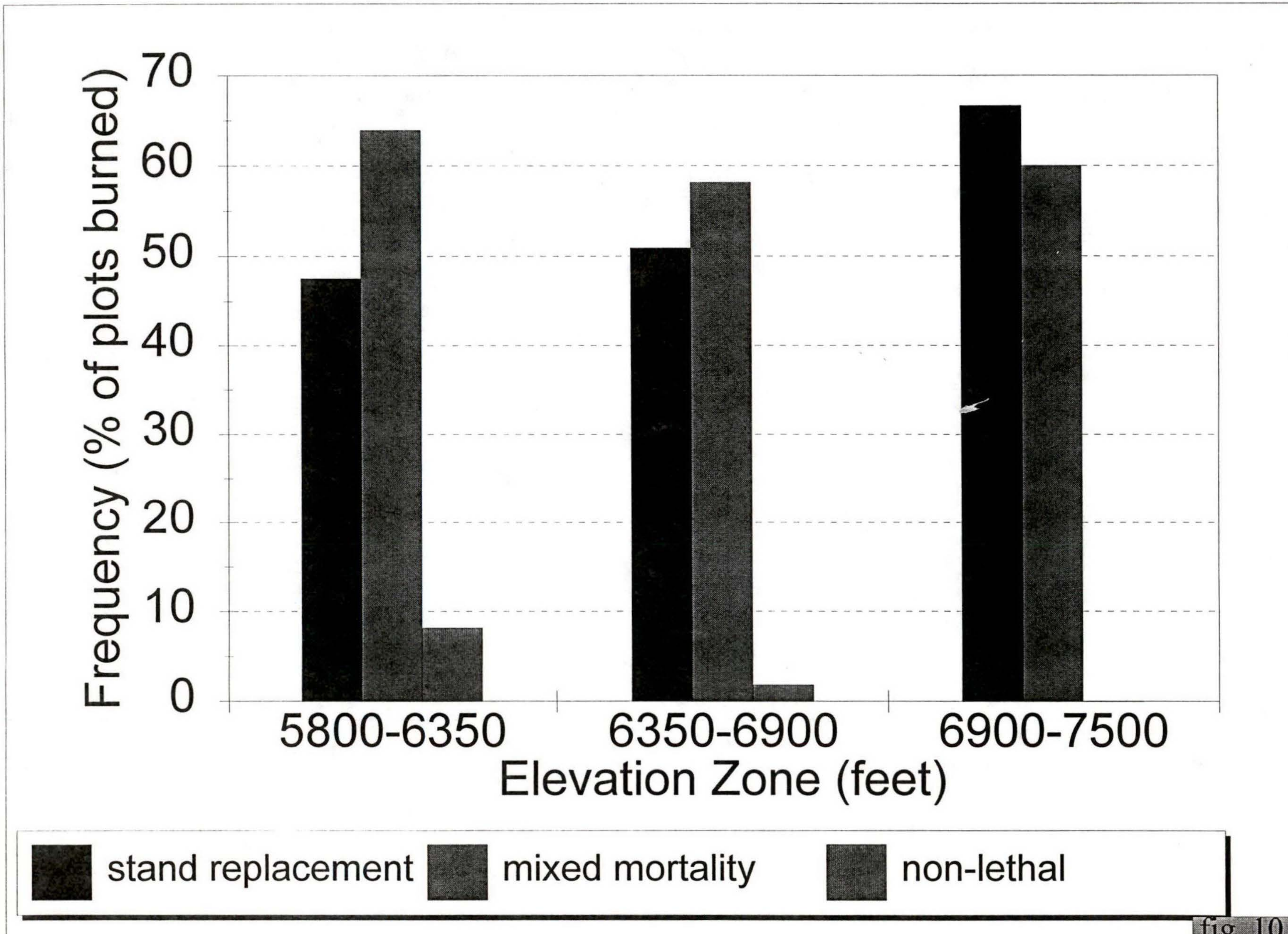

Change in Total Basal Area from 1900 to 1995
all study areas by elevation zone
Basal area (square feet per acre)
200
150
100
50
0
St Joe 4500-5800
Cow Cr 4500-5800
St. Joe 5800-6900
Cow Cr 5800-6900
Sweeny 5800-6900
St. Joe 6900-7500
Cow Cr 6900-7500
Elevation zone (feet)
1900
1995

Figure 8

Frequency (% of face burned)
100
80
60
40
20
0
1676
1724
1740
1786
1798
1840
1858
1910
Year of Event
St.Joe
Cow Cr.
Sweeny

Figure 9



Frequency (% of plots burned)
70
60
50
40
30
20
10
0
5800-6350
6350-6900
6900-7500
Elevation Zone (feet)
stand replacement
mixed mortality
non-lethal

fig. 10

Diameter Distribution for Ponderosa Pine

A comparison between 1900 and 1995
For elevations 4500 to 5800 feet

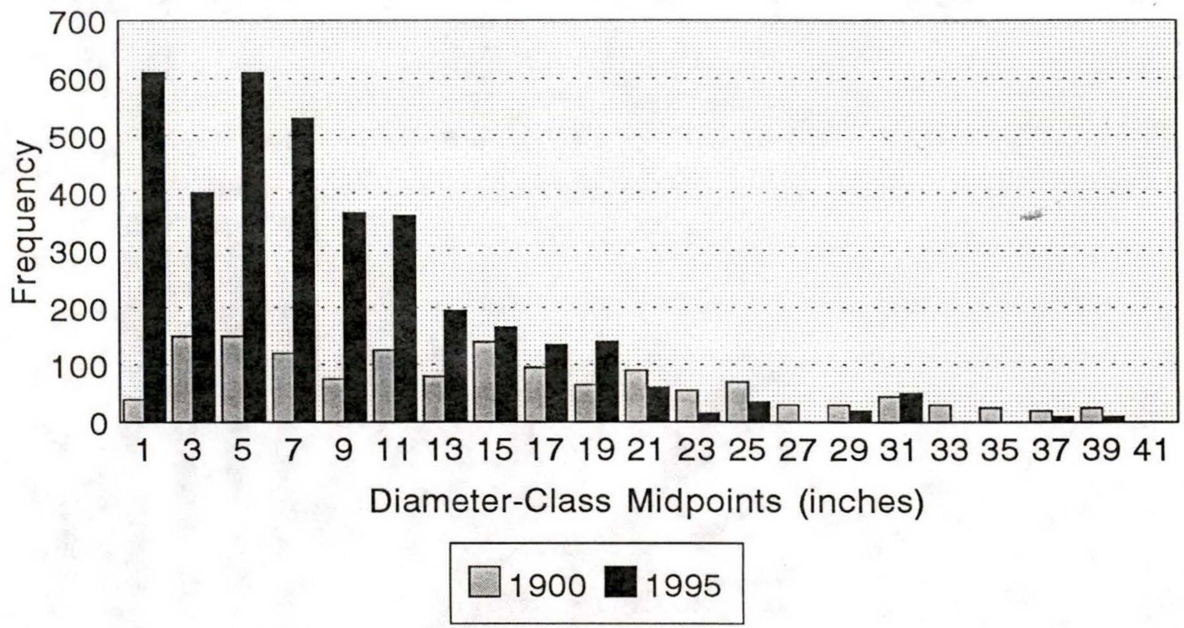


Figure 11a

Diameter Distribution for Douglas-fir

A comparison between 1900 and 1995
For elevations 4500 to 5800 feet

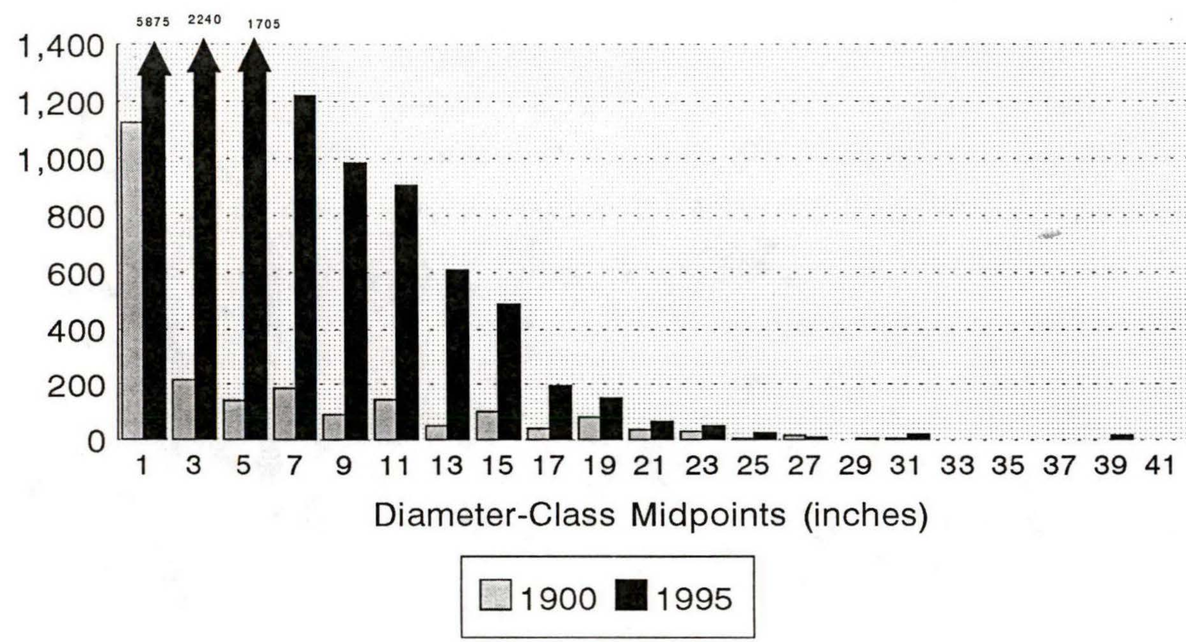


Figure 11b

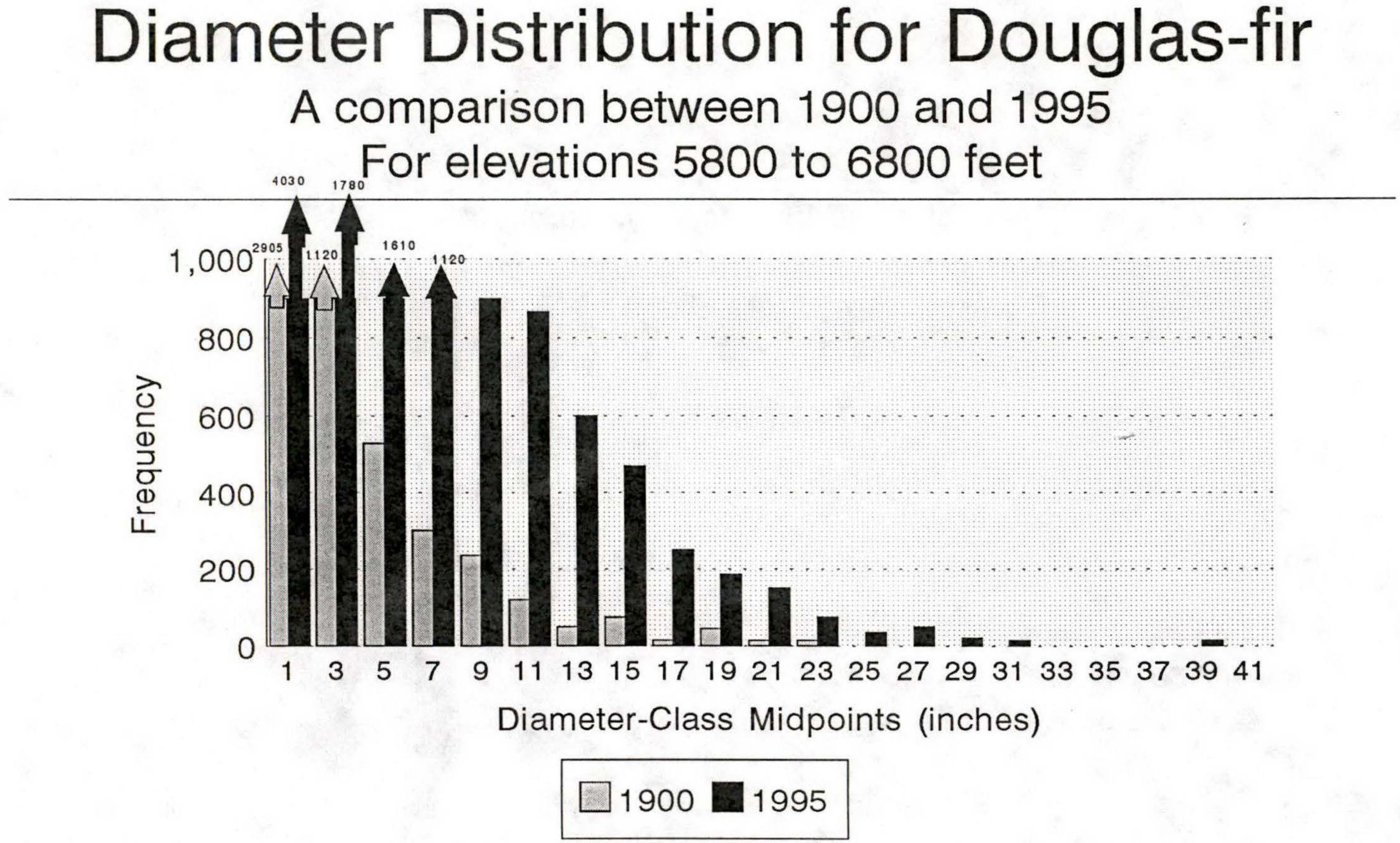

Diameter Distribution for Douglas-fir
A comparison between 1900 and 1995
For elevations 5800 to 6800 feet
4030
1780
2905
1120
1610
1120
1,000
800
600
400
200
0
Frequency
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41
Diameter-Class Midpoints (inches)
1900
1995

Figure 11c

Diameter Distribution for Lodgepole Pine

A comparison between 1900 and 1995
For elevations 6800 to 7500 feet

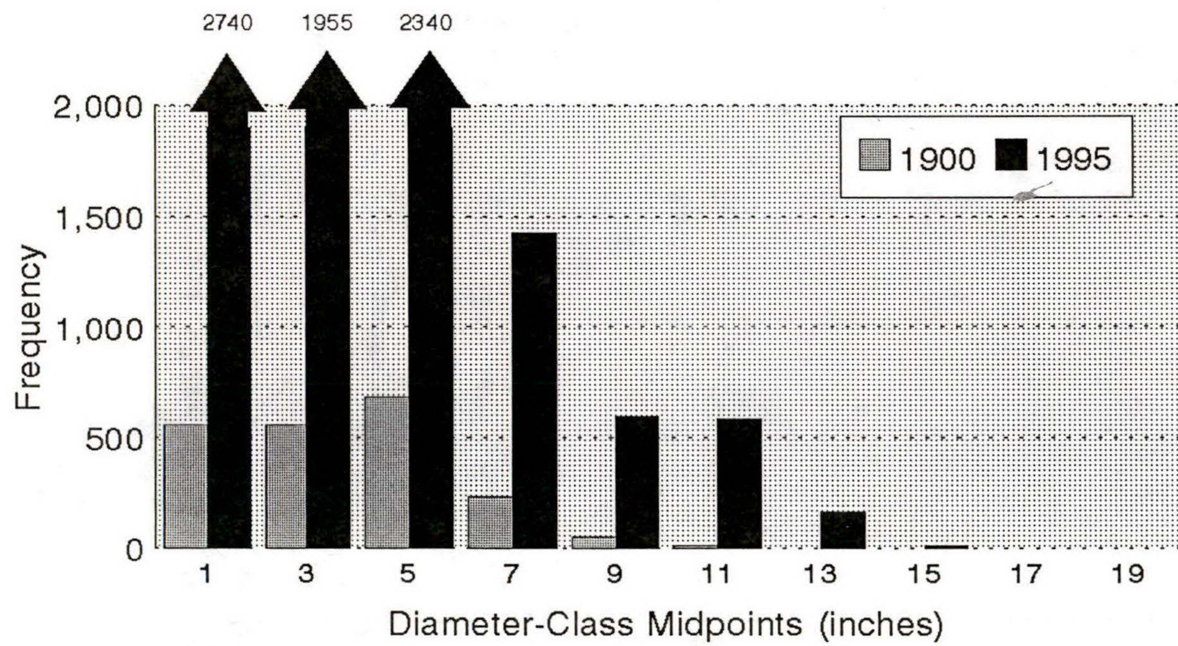
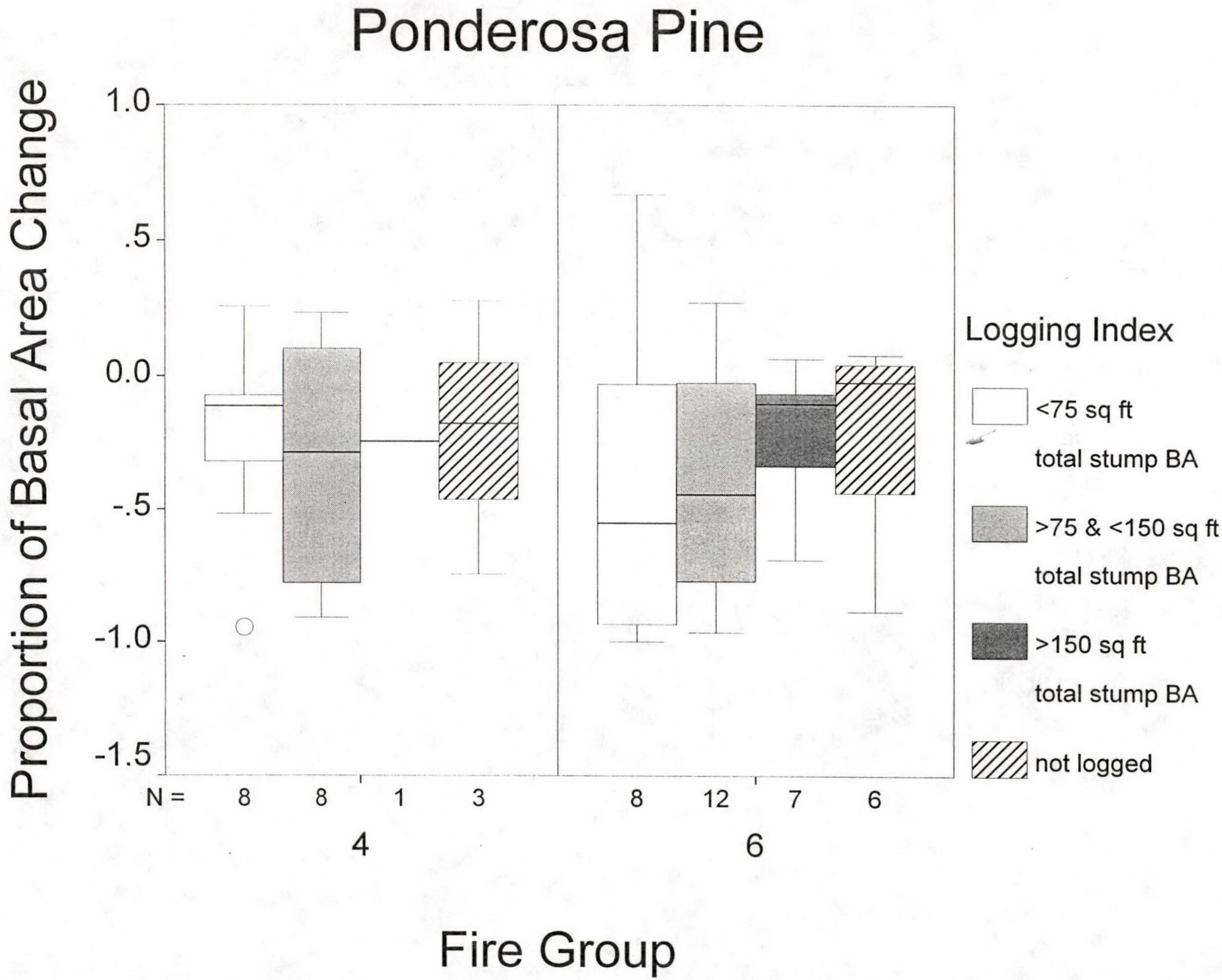
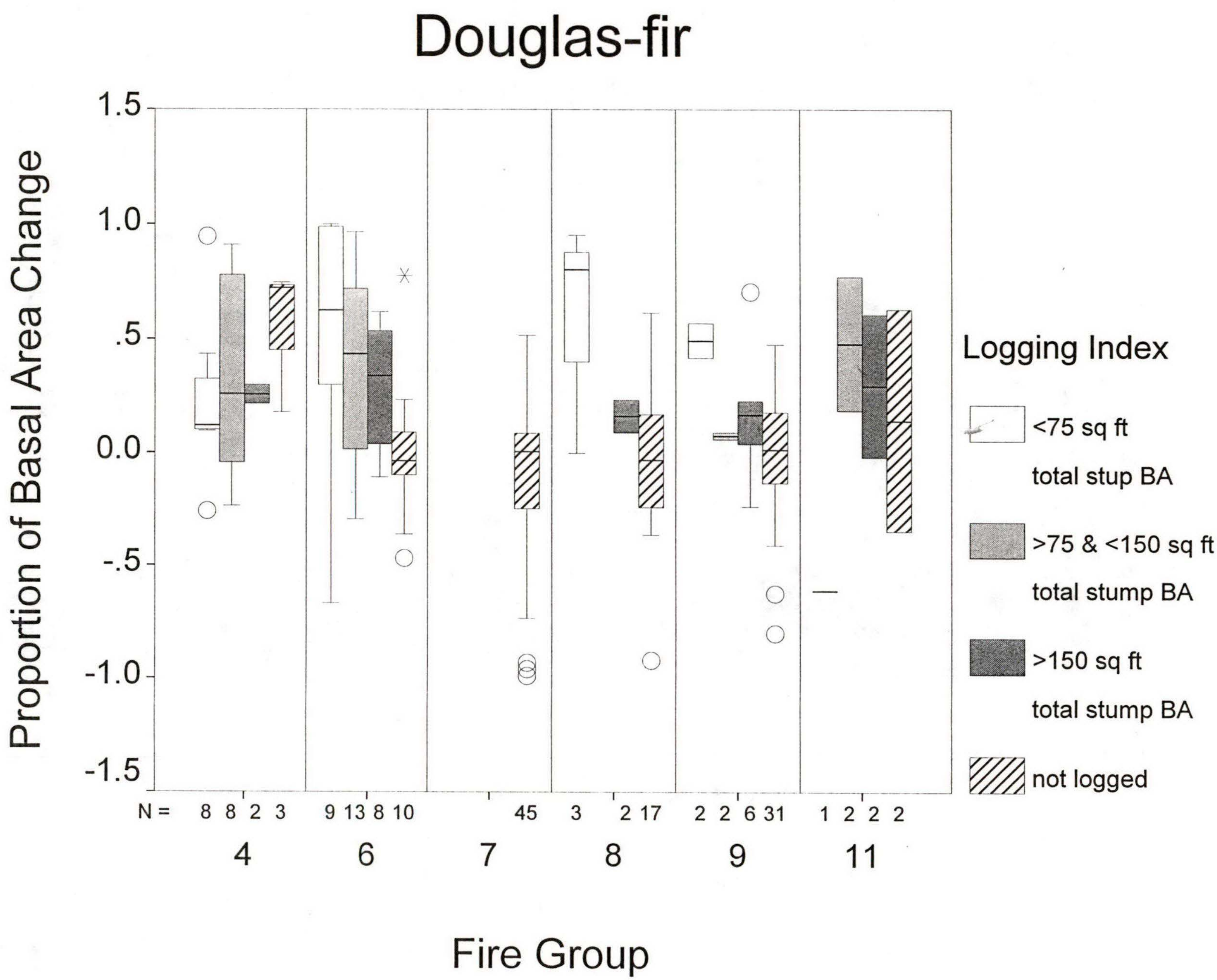


FIGURE [illegible].



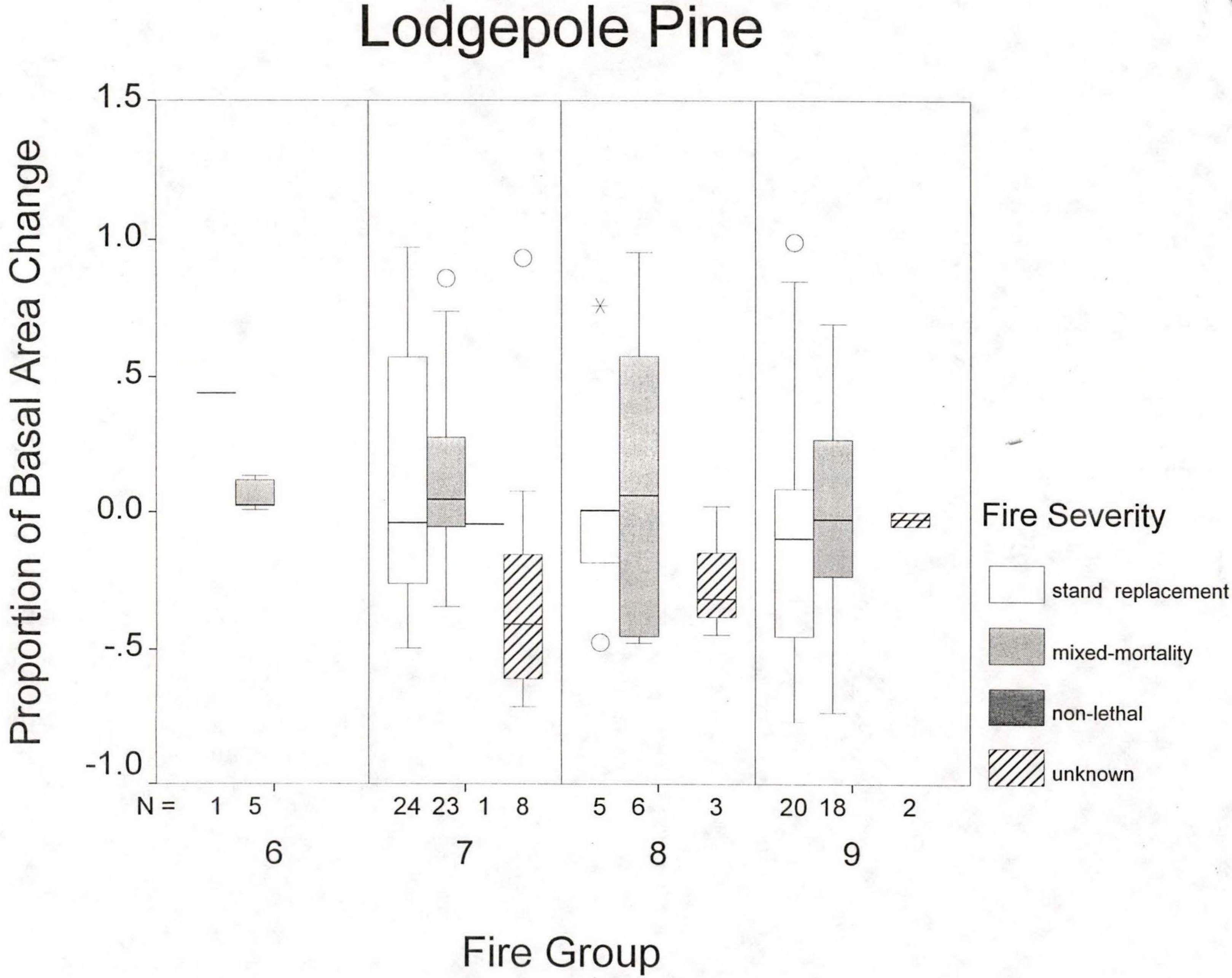
Ponderosa Pine
Proportion of Basal Area Change
1.0
.5
0.0
-.5
-1.0
-1.5
N =
8
8
1
3
8
12
7
6
4
6
Fire Group
Logging Index
<75 sq ft total stump BA
>75 & <150 sq ft total stump BA
>150 sq ft total stump BA
not logged

Figure 12a



Douglas-fir
Proportion of Basal Area Change
1.5
1.0
.5
0.0
-.5
-1.0
-1.5
N = 8 8 2 3 9 13 8 10 45 3 2 17 2 2 6 31 1 2 2 2
4
6
7
8
9
11
Fire Group
Logging Index
<75 sq ft total stup BA
>75 & <150 sq ft total stump BA
>150 sq ft total stump BA
not logged

Figure 12b



Lodgepole Pine
Proportion of Basal Area Change
1.5
1.0
.5
0.0
-.5
-1.0
N = 1 5 24 23 1 8 5 6 3 20 18 2
6
7
8
9
Fire Group
Fire Severity
stand replacement
mixed-mortality
non-lethal
unknown

Figure 13a

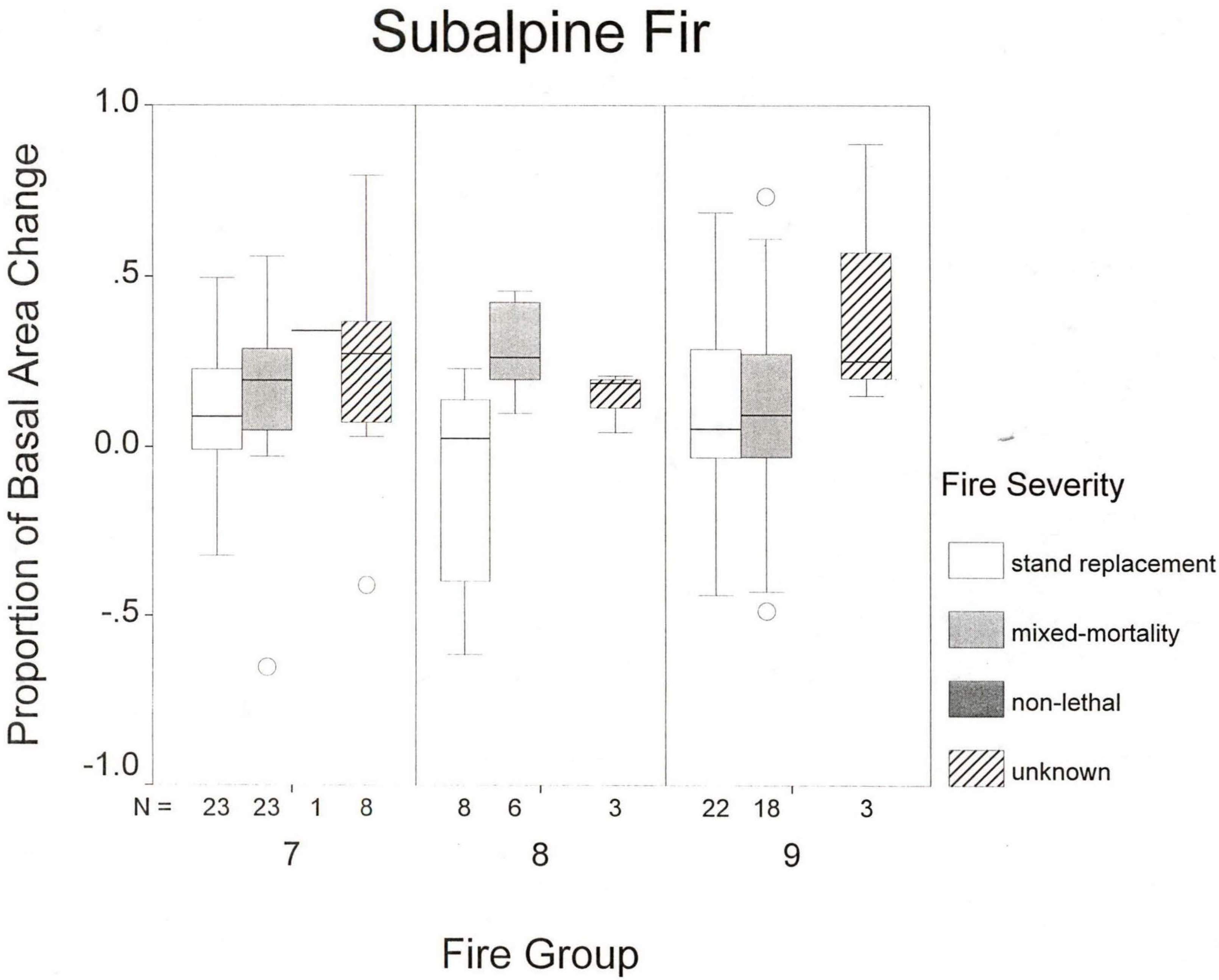

Subalpine Fir
Proportion of Basal Area Change
1.0
.5
0.0
-.5
-1.0
N =
23
23
1
8
8
6
3
22
18
3
7
8
9
Fire Group
Fire Severity
stand replacement
mixed-mortality
non-lethal
unknown

Figure 13b

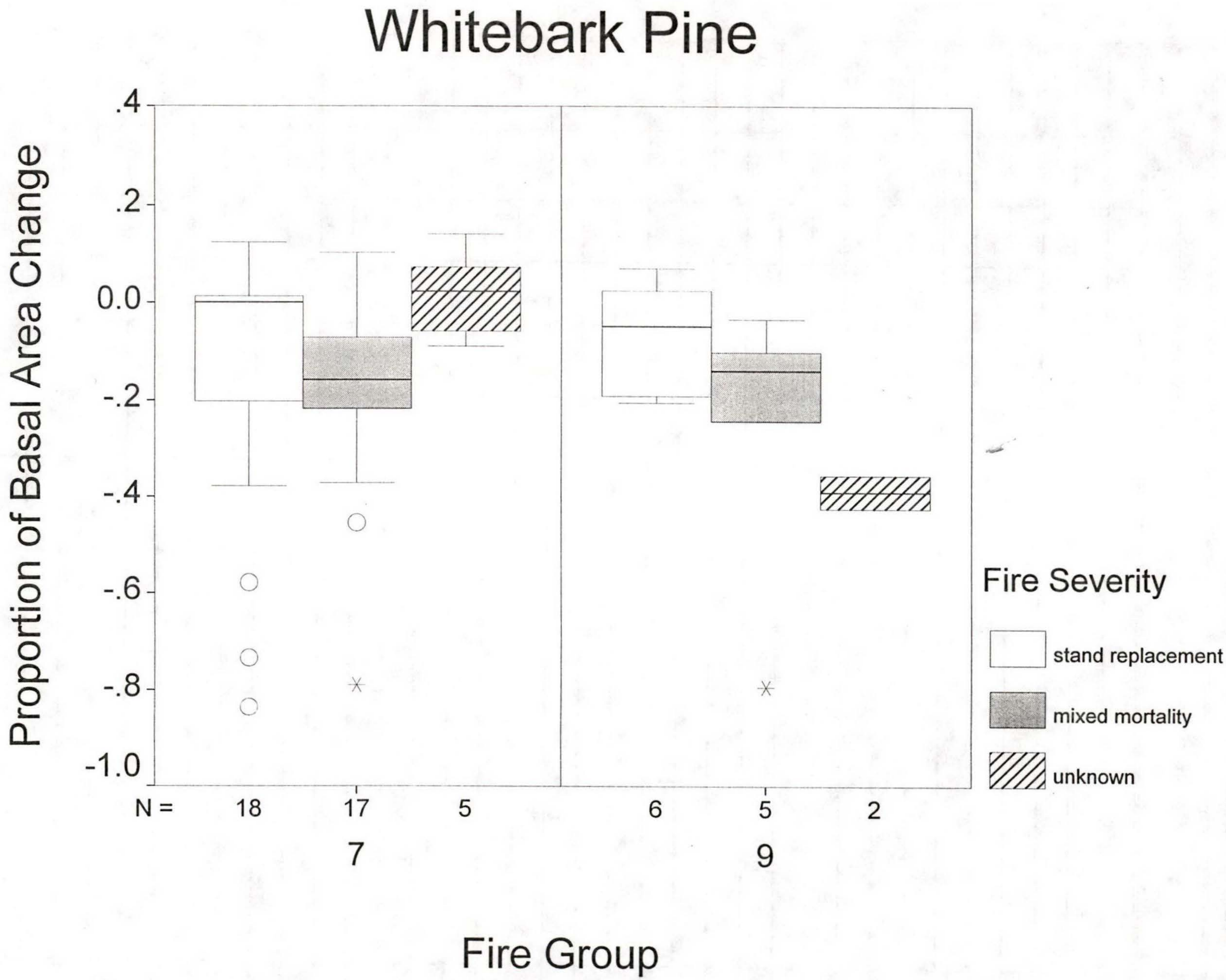

Whitebark Pine
Proportion of Basal Area Change
.4
.2
0.0
-.2
-.4
-.6
-.8
-1.0
N =
18
17
5
6
5
2
7
9
Fire Group
Fire Severity
stand replacement
mixed mortality
unknown

Figure 13c

APPENDIX A

—TRANSECT LOG FOR USE IN ESTABLISHING CONTROL LINE AND TRANSECTS

DATE:	**CREW:**
TRANSECT:	**STARTING POINT:**

TP	Point Description / Comment	Distance and direction to next point					
		Az	Ds	S%	SCF	Dh	TOT
		XX	XX	XX	XX	XX	XX

TP = turning point (numbered consecutively); Az = azimuth (degrees); Ds = slope distance; S% = percent slope; SCF = slope correction factor; Dh = horizontal distance (Ds*SCF); TOT = cumulative distance travelled on transect or control line.

APPENDIX B

Transect:	Plot:	Date:	H.T.:
elevation:		slope: aspect:	time started:
GPS reference:		slope position:	time completed:

Live tree tally: Diameter at breast height, all trees >4.5 ft., inside 1/10th acre plot or 1/5th

		1	3	5	7	9	11	13	15	17	19	21	23	25	27	
PIPO																
PSME																
LAOC																
PICO																
PIEN																
ABLA																
ABGR																

Record snags >= 5" (decay class: 1=fine twigs, bark intact, 2= bark peeling off, no fine twigs, 3=no bark)

species															
diameter															
decay class															
broken/fallen															

Increment core data:

No.	SPP	DBH	Core Ht.	Board	Slot	Field count	Comments

On-site descriptive interpretation of stand history.

# entries:	logging1:	logging2:	logging3:	structure class:
# cohorts:	cohort1:	cohort2:	cohort3:	cohort4:

Fire history:

Other disturbances:

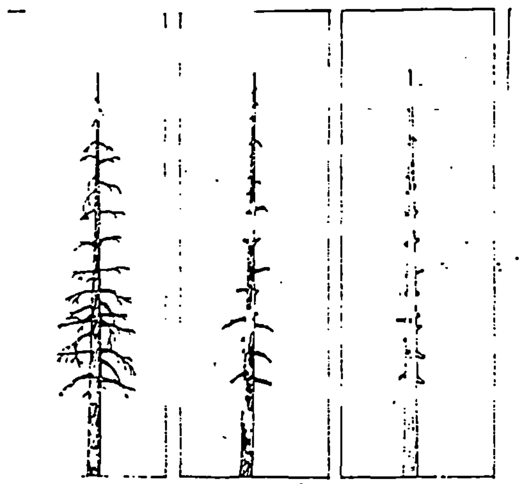
Evidence of previous stand:

APPENDIX B (CONT.)

1/10th or 1/5th acre plot.
Record stump characteristics for stumps >=5"

Spp	Diameter (in.)	Height (ft)	# fire scars	charred? (Y/N)	Rot pattern	Comments:

APPENDIX C



DECAY CLASS 1 2 3

APPENDIX D

------------------------- ponderosa pine-------------------------

N = 104   Regression Models for Dependent Variable: LOGAGE

Number in Model	R-square	MSE	Variables in Model
1	0.39378351	0.26283783	LOGDBH
1	0.08279848	0.39767190	ELEV
1	0.03152914	0.41990079	STAGE
1	0.01191645	0.42840428	BA
2	0.47400595	0.23031370	LOGDBH ELEV
2	0.40781631	0.25929573	LOGDBH STAGE
2	0.39900956	0.26315189	LOGDBH BA
2	0.10082688	0.39371526	STAGE ELEV
2	0.09098509	0.39802462	BA ELEV
2	0.04256027	0.41922809	BA STAGE
3	0.47965155	0.23012011	LOGDBH STAGE ELEV
3	0.47691251	0.23133143	LOGDBH BA ELEV
3	0.41274105	0.25971076	LOGDBH BA STAGE
3	0.10869288	0.39417373	BA STAGE ELEV
4	0.48249494	0.23117438	LOGDBH BA STAGE ELEV

------------------------- Douglas-fir-------------------------

N = 361   Regression Models for Dependent Variable: LOGAGE

Number in Model	R-square	MSE	Variables in Model
1	0.36262138	0.21520690	ELEV
1	0.23366214	0.25874918	LOGDBH
1	0.09846211	0.30439863	BA
1	0.00617535	0.33555868	STAGE
2	0.54803103	0.15303076	LOGDBH ELEV
2	0.37341086	0.21215486	BA ELEV
2	0.36286235	0.21572645	STAGE ELEV
2	0.29800380	0.23768671	LOGDBH BA
2	0.23773644	0.25809244	LOGDBH STAGE
2	0.10499840	0.30303580	BA STAGE
3	0.55158800	0.15225170	LOGDBH BA ELEV
3	0.54807147	0.15344569	LOGDBH STAGE ELEV
3	0.37383452	0.21260529	BA STAGE ELEV
3	0.30245093	0.23684254	LOGDBH BA STAGE
4	0.55167658	0.15264922	LOGDBH BA STAGE ELEV

APPENDIX D (cont.)

------------------------------ western larch ------------------------------

N = 67 Regression Models for Dependent Variable: LOGAGE

Number in Model	R-square	MSE	Variables in Model
1	0.36695352	0.21143796	LOGDBH
1	0.12384422	0.29263663	ELEV
1	0.03406151	0.32262412	STAGE
1	0.02010853	0.32728442	BA
2	0.47679701	0.17748063	LOGDBH ELEV
2	0.39441341	0.20542675	LOGDBH BA
2	0.37814875	0.21094404	LOGDBH STAGE
2	0.13440651	0.29362615	BA ELEV
2	0.13020838	0.29505023	STAGE ELEV
2	0.04587494	0.32365778	BA STAGE
3	0.49335585	0.17459154	LOGDBH BA ELEV
3	0.47681466	0.18029170	LOGDBH STAGE ELEV
3	0.39997765	0.20677003	LOGDBH BA STAGE
3	0.13847043	0.29688644	BA STAGE ELEV
4	0.49368457	0.17729243	LOGDBH BA STAGE ELEV

------------------------------ lodgepole pine ------------------------------

N = 299 Regression Models for Dependent Variable: LOGAGE

Number in Model	R-square	MSE	Variables in Model
1	0.08407088	0.23925604	LOGDBH
1	0.04488737	0.24949143	BA
1	0.02781676	0.25395055	ELEV
1	0.01040606	0.25849852	STAGE
2	0.11391993	0.23224092	LOGDBH BA
2	0.10598724	0.23432007	LOGDBH ELEV
2	0.09469153	0.23728067	LOGDBH STAGE
2	0.06297298	0.24559408	BA ELEV
2	0.06175914	0.24591222	BA STAGE
2	0.04254418	0.25094845	STAGE ELEV
3	0.12982091	0.22884641	LOGDBH BA STAGE
3	0.12905112	0.22904886	LOGDBH BA ELEV
3	0.12046131	0.23130788	LOGDBH STAGE ELEV
3	0.08342958	0.24104676	BA STAGE ELEV
4	0.14816321	0.22478460	LOGDBH BA STAGE ELEV

APPENDIX D (cont.)

------------------------- Engelman spruce-------------------------

N = 62   Regression Models for Dependent Variable: LOGAGE

Number in Model	R-square	MSE	Variables in Model
1	0.16054942	0.13939270	LOGDBH
1	0.07935322	0.15287552	ELEV
1	0.06676164	0.15496638	STAGE
1	0.02632443	0.16168107	BA
2	0.28578011	0.12060799	LOGDBH ELEV
2	0.19202479	0.13644015	LOGDBH STAGE
2	0.18415761	0.13776865	LOGDBH BA
2	0.15877893	0.14205427	STAGE ELEV
2	0.10541433	0.15106577	BA STAGE
2	0.08704257	0.15416815	BA ELEV
3	0.32339484	0.11622605	LOGDBH STAGE ELEV
3	0.28883119	0.12216333	LOGDBH BA ELEV
3	0.22411432	0.13328028	LOGDBH BA STAGE
3	0.17298734	0.14206278	BA STAGE ELEV
4	0.32986902	0.11713346	LOGDBH BA STAGE ELEV

------------------------- subalpine fir-------------------------

N = 312   Regression Models for Dependent Variable: LOGAGE

Number in Model	R-square	MSE	Variables in Model
1	0.06908319	0.12736569	LOGDBH
1	0.00645166	0.13593478	ELEV
1	0.00004415	0.13681144	STAGE
1	0.00002016	0.13681472	BA
2	0.09709710	0.12393268	LOGDBH ELEV
2	0.07071522	0.12755386	LOGDBH BA
2	0.07038149	0.12759967	LOGDBH STAGE
2	0.00654810	0.13636146	BA ELEV
2	0.00647503	0.13637149	STAGE ELEV
2	0.00007023	0.13725061	BA STAGE
3	0.09853822	0.12413661	LOGDBH STAGE ELEV
3	0.09737157	0.12429726	LOGDBH BA ELEV
3	0.07236029	0.12774146	LOGDBH BA STAGE
3	0.00656344	0.13680208	BA STAGE ELEV
4	0.09896673	0.12448176	LOGDBH BA STAGE ELEV

APPENDIX D (cont.)

------------------------------ whitebark pine------------------------------

N = 60 Regression Models for Dependent Variable: LOGAGE

Number in Model	R-square	MSE	Variables in Model
1	0.51803176	0.10209193	LOGDBH
1	0.13077696	0.18412139	BA
1	0.00450712	0.21086824	ELEV
1	0.00030103	0.21175918	STAGE
2	0.55597232	0.09570534	LOGDBH BA
2	0.53355453	0.10053725	LOGDBH ELEV
2	0.52372196	0.10265656	LOGDBH STAGE
2	0.17371636	0.17809646	BA ELEV
2	0.13118934	0.18726270	BA STAGE
2	0.00516318	0.21442627	STAGE ELEV
3	0.56133149	0.09623863	LOGDBH BA STAGE
3	0.55783121	0.09700655	LOGDBH BA ELEV
3	0.53751130	0.10146449	LOGDBH STAGE ELEV
3	0.17601887	0.18077162	BA STAGE ELEV
4	0.56257864	0.09770984	LOGDBH BA STAGE ELEV